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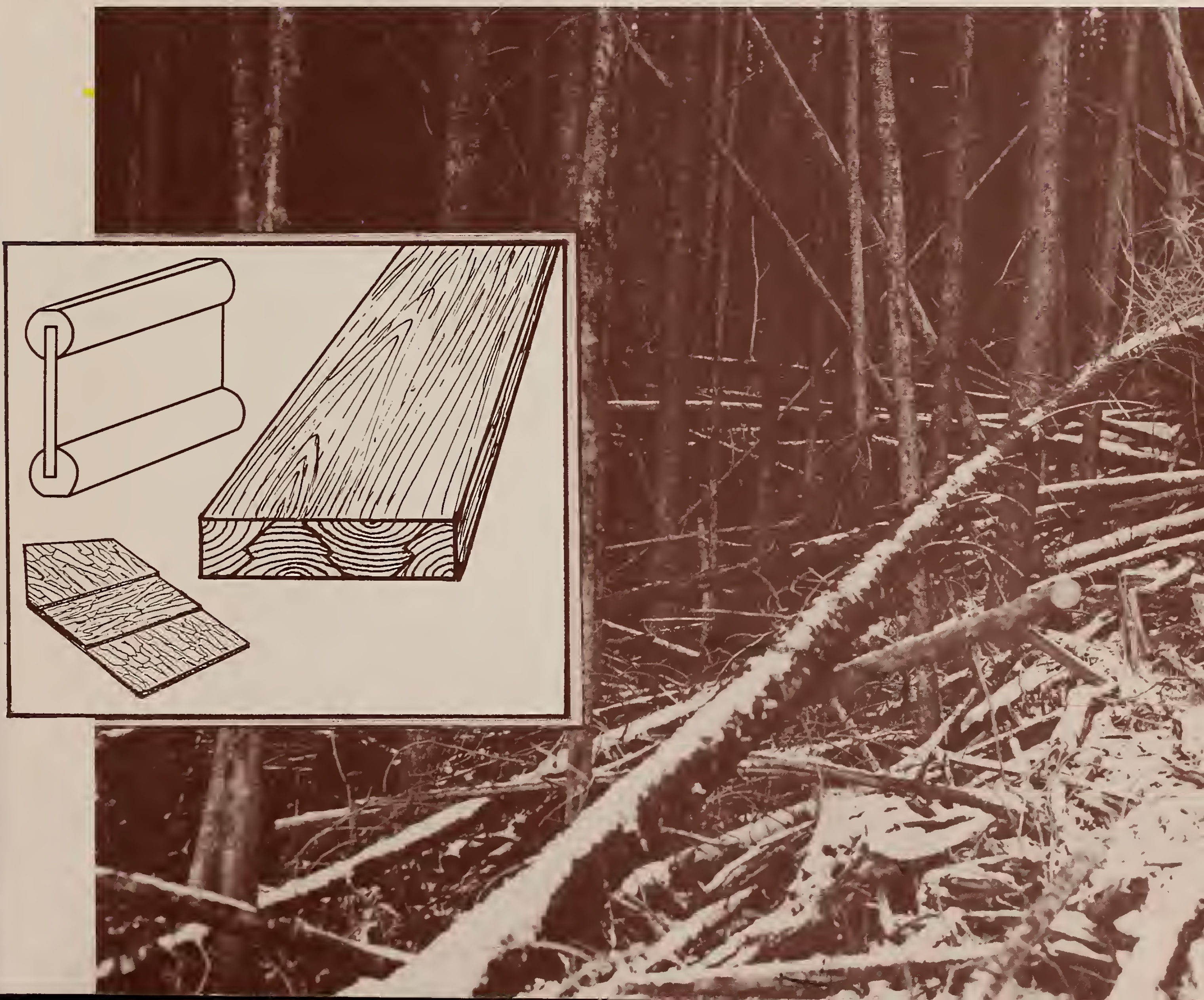
Proposed Wood Products Plant To Utilize Sub-Sawlog Size and Dead Lodgepole Pine in Northwestern Montana— A Technical and Economic Feasibility Analysis

Peter Koch
Charles E. Keegan III
Edwin J. Burke
Darrell L. Brown



THE AUTHORS

PETER KOCH is President, Wood Science Laboratory, Inc., Corvallis, MT.

CHARLES E. KEEGAN III is Director of Forest Industry Research, Bureau of Business and Economic Research, University of Montana, Missoula.

EDWIN J. BURKE is Associate Professor of Wood Science and Associate Dean, School of Forestry, University of Montana, Missoula.

DARRELL L. BROWN is Assistant Professor, School of Business Administration, University of Montana, Missoula.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

RESEARCH SUMMARY

This report proposes—and evaluates the technical and economic feasibility of—an integrated multiproduct facility designed to utilize small-diameter (sub-sawtimber size) lodgepole pine in the Libby-Troy area of northwestern Montana. Harvesting and silvicultural activities related to the manufacturing operation are designed to help solve a major public forest management problem in the area by removing—at minimal public cost—stands of stagnated, bark-beetle-infested, and dead timber to facilitate rapid regeneration into vigorous new stands of greatly increased productivity.

The facility is designed to employ 271 people in the manufacturing plant to process 200,000 tons (ovendry-weight basis) of stemwood annually. Trees harvested will be predominantly lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) in diameter classes from 3 to 7 inches. Some associated species will also be harvested. Several manufacturing centers will be integrated in the plant to produce the following products:

- market OSB (oriented-strand board)
- fabricated joists with webs of waferboard (structural flakeboard with randomly oriented flakes) and flanges of minimally machined lodgepole pine dowels
- edge-glued lumber panels for mill work
- studs
- tree props and fence rails
- pulp chips
- particleboard furnish

The facility will generate an estimated $40 million in revenue in its first year of full production and will operate for 20 years. It will require $62 million in capital and have annual operating costs before depreciation of $30 million at full production.

Major Products and Markets

The plant will use small-diameter lodgepole pine timber to manufacture fabricated and reconstituted products for uses historically filled by large-diameter old-growth timber, the supply of which is forecast to diminish in quality as well as quantity at the same time that consumption of wood products is projected to increase significantly. Specifically, the plant is designed to receive 90 percent of its revenue from three products—market OSB, fabricated joists, and edge-glued lumber panels.

The OSB is a structural panel made from 3-inch-long wood flakes about twice the thickness of a postage stamp, oriented in the panel to achieve maximum stiffness and strength. It has wide and growing application in residential and nonresidential construction and in industrial markets.

The fabricated joists will be made with flanges of lodgepole pine dowels 2⁵/8 inches in diameter and webs of ³/8-inch-thick waferboard. They will be manufactured in depths of 10, 12, 14, and 16 inches and designed for uses currently filled by solid-sawn 2 by 10 and 2 by 12 softwood structural lumber or by joists fabricated with solid-sawn lumber or parallel-laminated veneer flanges and plywood webs. Joists fabricated with minimally machined lodgepole pine dowels for flanges are lighter, drier, stiffer, stronger, and more uniform in mechanical properties than sawn lumber joists of comparable depth. A major advantage is quick availability from distributing yards in schedules of precise but nonstandard lengths (up to 64 feet) specified by builders. The joists may be slightly heavier than some fabricated joists currently on the market, but tests have shown the lodgepole pine joists have significantly superior mechanical properties—that is, the lodgepole pine joists warrant design values for stiffness and resistive moment that are significantly greater than competitive fabricated joists of comparable depth and price.

The edge-glued lumber panels are designed for sound-knotted grades of mill work. They will be produced by doweling, center ripping, kiln drying, and then moulding small-diameter lodgepole pine stem sections into trapezoidal shapes that will be edge-glued into panels 100 inches long by 48 inches wide. The sanded panels will be available in a range of thicknesses (1 to 3 inches) for use in mill work such as tabletops, doors, windows, stair treads, and wall panels. They may also find use as truck flooring.

The three products just described will provide 90 percent of plant revenues. The remaining 10 percent will come from production of small roundwood products (tree props and fence rails), studs, pulp chips, and particleboard furnish.

Raw Material Availability

The facility is designed to use the enormous—and presently unmerchantable—volumes of small-diameter lodgepole pine timber available from stagnant and overstocked stands in northwestern Montana.

Currently, little of this material is being used by industry, and available quantities greatly exceed the volumes required by the proposed plant. That is, over the 22-year life of the project the proposed plant would consume about half the tonnage available in the procurement area of sub-sawlog-size, marginal sawlog, and dead lodgepole pine timber.

Cash-Flow: 50 Percent Debt, 50 Percent Equity Financing

The financial analysis is based on the assumption that the project will be developed by a Fortune-500-type company, domestic or foreign, with a good credit rating and ready access to the financial markets. To summarize, a line of credit would be established (interest rate assumed to be 10 percent annually) to handle construction activities and to provide working capital for the initial phases of plant operation. Long-term financing for the facility will consist of a $31 million bond issue at 10 percent interest, and a $31 million common stock issue.

Average annual return on the equity investment of $31 million is estimated at 25.1 percent after corporate income taxes—over the 22-year life of the project.

Cash-Flow: Excluding Financing Flows

Because the return on investment varies as the project's financing varies, an additional analysis was performed calculating the return independently from the specific financing approach. This analysis estimated the average annual rate of return to all investors at 16.8 percent after corporate income taxes—over the 22-year life of the project.

FOREWORD

The Northern Region supports the efforts of Dr. Peter Koch and associates who worked in cooperation with the Intermountain Research Station, Montana Science and Technology Alliance, and the University of Montana for the development of a possible solution toward putting under management stands of stagnated lodgepole pine and the utilization of subsawtimber size and dead timber.

The primary source of timber for the proposed facility is the Kootenai and other National Forest areas within a 75-mile radius of Libby or Troy.

The facility will require 200,000 tons (ovendry basis) annually of subsawtimber size, dead, and marginal sawlogs. Most of the subsawtimber and dead sawlogs will be lodgepole pine.

The specific source of raw material will be through management of subsawtimber size lodgepole pine stands and the purchase of dead and marginal sawtimber directly from forest managers or from other purchasers. The acquisition of subsawtimber size lodgepole pine will be through commercial timber sales or service contracts with salvage rights, depending on the costs of treatment compared to the revenues derived.

The acreage to be harvested could range up to 2,500 acres annually. The resource data from the Kootenai National Forest, based on the final Forest Plan, are as follows:

1. Suitable timber base is 1,263,000 acres.

2. First decade allowable sale quantity (regulated) is 202 million board feet or 50.5 million cubic feet annually. Achieving the offering of the ASQ is dependent on funding levels received by the Forest and the ability to fully implement the provisions of the Forest Plan.

3. First decade programmed sell level (regulated plus unregulated) is 227 million board feet annually.

4. Conversion of 32,000 acres of stagnated lodgepole pine stands by the fifth decade.

There are additional resources in the Tally Lake District of the Flathead National Forest. These include approximately 20,000 acres of subsawtimber size lodgepole pine. Currently, most of it is unroaded. However, capital investment road funds are planned to access these areas.

The Region and National Forests involved, particularly the Kootenai, will make a reasonable attempt to make available the timber resource necessary to meet the anticipated needs of the proposed facility. Kootenai personnel believe the raw material exists to equal the needs of the operation for over a 10-year period, and most likely a 20-year period, if it is possible to economically utilize lodgepole pine (including stagnant, marginal sawtimber, dead sawtimber, and some green sawtimber) on slopes that may exceed 55 percent and at haul distance up to 75 miles while meeting the environmental requirements of the Forest Plan. In addition, competition for available resources is present and expected to increase. Existing industries will potentially compete more heavily in the future. Competition for subsawtimber size material will increase due to the new paper mill at Usk, WA, and the expected reductions in chip production at existing sawmills due to lower available timber supplies in the State of Montana.

We believe this proposal can be an important tool in achieving the desirable goal of putting extensive stands of stagnated lodgepole pine in northwestern Montana under management.

Christopher Risbrudt

for John W. Mumma
Regional Forester
Northern Region
Forest Service

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CHAPTER 1: INTRODUCTION

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This paper explores the technical and economic feasibility of establishing in northwestern Montana an integrated manufacturing plant designed to solve a land management problem on acreages growing lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), while simultaneously providing employment for significant numbers of Montana residents and providing an appropriate return for entrepreneurs on the multimillion dollar investment required. The proposed enterprise will harvest an extensive acreage of lodgepole pine annually and operate a major center for segmenting whole trees into components to maximize value. Products include tree props, fabricated joists, edge-glued lumber panels, and oriented-strand board (OSB)—a type of structural flakeboard. Most of the projected output will be marketed outside the State of Montana.

A single-product plant manufacturing structural flakeboard from lodgepole pine in Montana—while much simpler than a multiproduct plant—would appear to be uncompetitive for three reasons. First, the freight costs to West Coast, Southwest, and Midwest markets are significantly higher than those from locations closer to these markets. Second, the magnitude of the available wood resource, in stem sections 5 inches in diameter and larger, is such that a stand-alone flakeboard plant would be limited to perhaps 150 million ft^2 annually ($^3/_8$-inch basis); manufacturing costs, exclusive of wood costs, for such a small plant are significantly higher than those of much larger plants already in operation. Finally, harvesting costs of sub-sawlog-size lodgepole pine (the resource that is available in quantity) growing on Montana's steep terrain are probably higher than those for some other tree species on gentler ground.

The unusually good mechanical properties of roundwood from sub-sawlog-size lodgepole pines in Montana, however, offer the possibility of a multiplicity of products sufficiently high in average value to overcome the previously mentioned economic disadvantages. An integrated plant converting 67 percent of entire tree stemwood into a spectrum of such products appears to be viable; the products proposed (exclusive of pulp chips and other residues) have a net plant-gate value of $183 to $543 per ovendry ton of wood content, with average value of $285. Residues from the plant include some pulp chips, but most of the residue tonnage will be hog fuel burned for process heat required by the operation.

1-1 GENERAL DESCRIPTION OF THE MONTANA LODGEPOLE PINE SITUATION

Although most acreages dominated by lodgepole pine are solidly forested in lodgepole pine, some contain significant components of western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* var. glauca [Beissn.] Franco), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), or bigtooth aspen (*Populus grandidentata* Michx.). Growth potential in Montana varies from only slightly more than 20 ft^3 per acre per year to more than 100 ft^3 per acre per year. Annual precipitation varies from a low of slightly less than 20 inches to a maximum of near 40 inches. Terrain varies from nearly level to mostly steep; in aggregate, perhaps two-thirds of the lodgepole pine acreage is on slopes of less than 45 percent. A few of the acreages are stony and boulder strewn, but most are not excessively rocky. Mortality—primarily from mountain pine beetle attacks—varies from the preponderance of stems to virtually none of the stems. Defects in live trees that adversely affect utilization in solid wood products include porcupine scars (in some areas occurring on three-quarters of the stems and at several heights in each stem), stem crook, stem sweep, stem fork, cankers, fire scars, frost cracks, pith eccentricity and excessive compression wood content, excessive spiral grain, excessive taper, and excessive limbiness. Degree of defect varies greatly among and within acreages.

Accessibility of the lodgepole acreages also varies significantly. Most have roads to their perimeters, and many have some interior roads; but a few can be reached only on foot. All are within 50 miles of a railhead.

In virtually all of the acreages, stand type varies in a continuum. Classes of stands include "dog-hair" stands of trees less than 3 inches in d.b.h., pole stands with all trees live, pole stands with many dead trees, pole stands with dense understories of smaller trees, stands of sparsely stocked small sawtimber—usually over 200 years old, vigorous stands of large pole timber (that is, 6 or 7 inches in d.b.h.), stands of dead trees killed by bark beetles—many of suitable size for cabin logs, and stands of a variety of ages and generally low stocking containing relicts of past insect attacks as well as a range of smaller trees—usually suffering from mistletoe attack and cankers of various descriptions.

The preponderance of lodgepole cubic volume in Montana is found in trees less than 8 inches in d.b.h.—that is, in trees generally too small to yield sawlogs. Trees are typically about 60 to 100 years old, with few stands less than 40 years old and some over 200 years old.

Lodgepole pine stand types that have particular significance to the study can be described as sub-sawlog-size **stagnant** (fig. 1-1), **marginal sawlog** (fig. 1-2), and **dead sawtimber** (fig. 1-3).

Figure 1-1—Sub-sawlog-size stagnant stand of lodgepole pine at 4,200 feet in the Zulu Creek-Smoot Creek area of the Kootenai National Forest in Montana. The labeled trees measure $3^1/2$ to 4 inches in d.b.h.

Figure 1-2—Marginal sawlog stand of lodgepole pine looking south from the Middle Fork of Cottonwood Creek at 5,500 feet on the Deerlodge National Forest in Montana.

Figure 1-3—A stand of dead lodgepole pine sawtimber in Montana. The trees were killed by mountain pine beetles.

In the d.b.h. class from $3^1/2$ to 4 inches, trees are generally about 38 feet tall, with few shorter than 25 feet and few taller than 55 feet; stemwood-average specific gravity of such trees ranges from 0.36 to 0.52, but is generally about 0.43 (based on ovendry weight and green volume). In trees $3^1/2$ to 4 inches in diameter, crown ratios are mostly in the range from 25 to 70 percent, with average near 45 percent. Below-crown stem taper (inside bark) is generally more than 0.4 and less than 0.8 inch per 100 inches, and averages about 0.6 inch. Within-crown stem taper (inside bark) averages about 1.3 inches per 100 inches.

Data from Montana lodgepole stands selected for 1985 thinning studies suggest that an average unthinned acre might contain 1,360 live stems 3 inches in d.b.h. and larger, totaling 3,400 ft^3 of stemwood, or about 43 tons of stemwood (ovendry basis). Considering all Montana lodgepole stands, however, a more conservative estimate might be 1,000 live stems per acre measuring 3 inches in d.b.h. and larger, totaling 2,500 ft^3 of stemwood, or about 31 tons of stemwood, ovendry. Even this lower estimate may prove too high on some lodgepole pine acreages in Montana.

1-2 CURRENT STUMPAGE VALUES VS. COST OF SELLING THE STUMPAGE

In discussing the stumpage value of lodgepole pine in Montana, it is necessary to differentiate the stands by d.b.h.

In northwestern Montana, sawtimber stands comprised mostly (80 percent or more) of live trees 9 inches in d.b.h. and larger typically have a stumpage value (1988) of about \$60 to \$80 per thousand board feet (M bd ft) Scribner scale, with sale size ranging from a few acres up to 1,000 acres. When clearcut, such stands may yield 10 to 12 M bd ft per acre based on Scribner log scale.

The sawtimber-size, mostly live lodgepole pine just described is not the subject of this analysis, however. Our concern is with the extensive sub-sawlog-size stagnant, marginal sawlog, and dead-timber stands. In most areas where such problem stands of lodgepole pine grow in Montana, post and pole operators nibble away at them, each cutting 1 to 3 acres annually in close proximity to existing roads; such post and pole operations are sometimes used to achieve cosmetic thinning along these roads. These operators generally pay a stumpage fee of \$5 to \$7 per thousand lineal feet of product.

In the problem stands, firewood stumpage values sometimes exceed stumpage values for other uses. Dead-timber stumpage is frequently sold for \$1 per M bd ft Scribner scale.

Occasionally, a sawlog sale of 15 to 500 acres is made in these problem stands, but virtually always at a stumpage cost less than that required to prepare the sale. Stumpage fees usually are in the \$6 to \$20 range, with some sales made at \$1 per M bd ft (Scribner log scale), and few as high as \$25.

Costs of preparing and executing a small-acreage, low-volume sawlog sale, exclusive of road construction costs, vary greatly among ownerships and also depend on the characteristics of the sale area. Sale costs per M bd ft of sawlogs are inversely related to sale acreage and to timber volume sold per acre. Sales on the areas studied usually encompass less than 40 acres, with lodgepole pine sawlog volume generally less than 8,000 bd ft per acre.

The direct costs to Forest Service Ranger Districts (or equivalent on State or Bureau of Land Management forests) were reported as low as \$2 in one area, but more typically are \$12 to \$25 per M bd ft, Scribner scale. When all appropriate direct and indirect costs within Ranger Districts, Supervisors' Offices, and Regional Headquarters are included, however, total sales costs per M bd ft of lodgepole pine sold in small tracts appear to be in the range from \$40 to \$60, with one National Forest reporting total costs of \$85. Such costs include not only those incurred by technicians, timber sales officers, and road planning engineers, but also those incurred by specialists in silviculture, wildlife habitat, landscape esthetics, watershed quality, archeology, and law (together with all supporting staff in Supervisors' Offices and Regional Headquarters).

Volumes of forest residues resulting from sawlog sales in problem lodgepole pine stands are generally great because most of the sawlog operators have no profitable outlet for sub-sawlog-size stems.

1-3 MANAGEMENT OBJECTIVES AND SILVICULTURAL CONSIDERATIONS

With virtually no exceptions, the land managers have concluded that thinning more-or-less stagnated stands that are 70 to 100 years old is an uneconomic procedure; this is so because products recovered in such thinning have low value, growth response is not outstanding, and thinning cost is great.

With almost no exceptions, the land managers are seeking some methodology to replace stagnated and unmarketable stands of lodgepole pine with new vigorous stands of the same species—and they want to do this without expending significant amounts of money. They visualize that this must be done by phased clearcutting and natural regeneration, but they have very few stumpage purchasers willing to build the necessary temporary roads, clearfell all diameter classes of all species, and leave the acreage with no more than 25 tons (ovendry) of slash per acre and with sufficient seed distributed on exposed mineral soil to ensure natural regeneration (fig. 1-4). When the managers contract such stand replacement operations, they incur costs of \$200 to \$700 per acre—costs that they find hard to economically justify. Most of the managers do not find it necesary to plant such clearcut areas if the seedbed is properly prepared with mineral soil adequately exposed and if viable seeds are available from serotinous cones on the ground or from adjacent trees bearing open cones.

Assuming that stand replacement can be accomplished with little or no expenditures, most of the managers think that they can internally fund thinning of the regenerated stands when the trees are 15 to 20 feet tall. Cost of such

Figure 1-4—Lodgepole pine clearcut with a steep-slope feller buncher. Small stems were crushed. All slash was left on the ground unpiled and unburned. Regeneration will be natural. The access road is temporary.

precommercial thinning is usually $60 to $85 per acre, but may be as high as $300 per acre if vegetation is dense in high-rainfall areas.

In virtually all cases, the managers must give great consideration to improvement of wildlife habitat, protection of stream quality, and protection of esthetic values—but these considerations are not generally seen as prohibiting planned stand replacement as long as clearcuts do not exceed 40 acres, are spaced to maintain elk or deer hiding cover, do not disturb streams, and are located and contoured to be visually acceptable.

While prescribed burning or wildfire might appear to offer a solution on some acreages, few managers are willing to embrace the idea of deliberately wasting the enormous tonnages of wood that would be consumed by such fires. And such fires would offer limited opportunity for protecting stream quality, wildlife habitat, and esthetic quality of the forest.

1-4 SUMMARY OF THE PROBLEM

In brief, land managers face the problem of how to clearcut and regenerate large acreages of stagnated or otherwise unproductive stands of lodgepole pine without large expenditures of funds to cover the direct costs. Additionally, managers must accomplish this stand replacement according to a management plan without jeopardizing the other values of the forest—that is, wildlife habitat, stream quality, and esthetic quality. Silviculturally, the goal is to replace these stagnant stands, with vigorous new stands that will be thinned to a prescribed stocking density when the new trees attain a height of about 15 to 20 feet. Additionally, harvesting the stagnant stands should yield a positive contribution to the economy—as contrasted to waste through destruction by fire, or by insects and disease.

Finally, the industrial manager of the proposed operation—who harvests, prepares the site, and utilizes the trees—must make an appropriate profit on the investment in harvesting, transport, and conversion facilities. This return, after taxes, should be at least 15 percent annually on the entire investment, assuming no funds have been borrowed.

CHAPTER 2: RESOURCE DATA, TERRAIN EVALUATION, PLANT SITE SELECTION, AND HARVESTING PROCEDURES

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2-1 MONTANA TIMBER RESOURCE DATA

Some 20.2 million acres, roughly 22 percent of the State of Montana, are covered with forest. Nearly three-fourths of Montana's forest land is publicly owned—most under administration of Federal agencies. The Forest Service has the most; its 13.8 million acres is 68 percent of the total and 93 percent of the publicly administered forest land, as follows (Green and others 1985):

Owner group	Area	Percent of total
	Thousand acres	
Public		
Forest Service	13,817.2	68
Other public	1,053.4	6
Total	14,870.6	74
Private	5,355.4	26
Total	20,226.0	100

Nearly 16 million acres are classed as productive timberland. Green and others (1985) estimated Montana's area of productive forest land **available** for growing and harvesting industrial wood products—the **commercial timberland** base—to be 13.6 million acres. The same general ownership pattern evident in the total forest land holds for the forest land classed as commercial timberland. Sixty-six percent is under public administration, mostly Federal. Of the remainder under private ownerships (34 percent), about one-third is owned by forest industries and about two-thirds is owned by farmers or ranchers (Green and others 1985).

Ownership class	Montana's commercial forest area	Percent of total
	Thousand acres	
National Forest	8,161.8	60
Other public	759.3	6
Forest industry	1,601.3	12
Farmers and other private	3,048.9	22
Total	13,571.3	100

Forests in Montana contain 27 species of trees—17 conifers and 10 hardwoods. How and where they grow depends on such things as elevation, available moisture, and soil characteristics. As a general rule, where there are mountains there are forests. The larger, wide, low-elevation valleys generally are not forested except for hardwoods growing along the streams.

The most heavily forested area of Montana is west of the Continental Divide (fig. 2-1) where the high mountain ranges trigger the release of large amounts of moisture from westerly airflows coming from the Pacific Ocean. There the nature of the forest changes quite noticeably over relatively short distances because the habitat conditions change rather rapidly with respect to elevation and moisture. East of the Divide the climate is much drier than west of the Divide. Consequently, the eastern Montana forests are restricted to higher elevations and exist in scattered patches (Green and others 1985).

Figure 2-1—Forested areas in Montana—depicted by shading. (Drawing after Green and others 1985.)

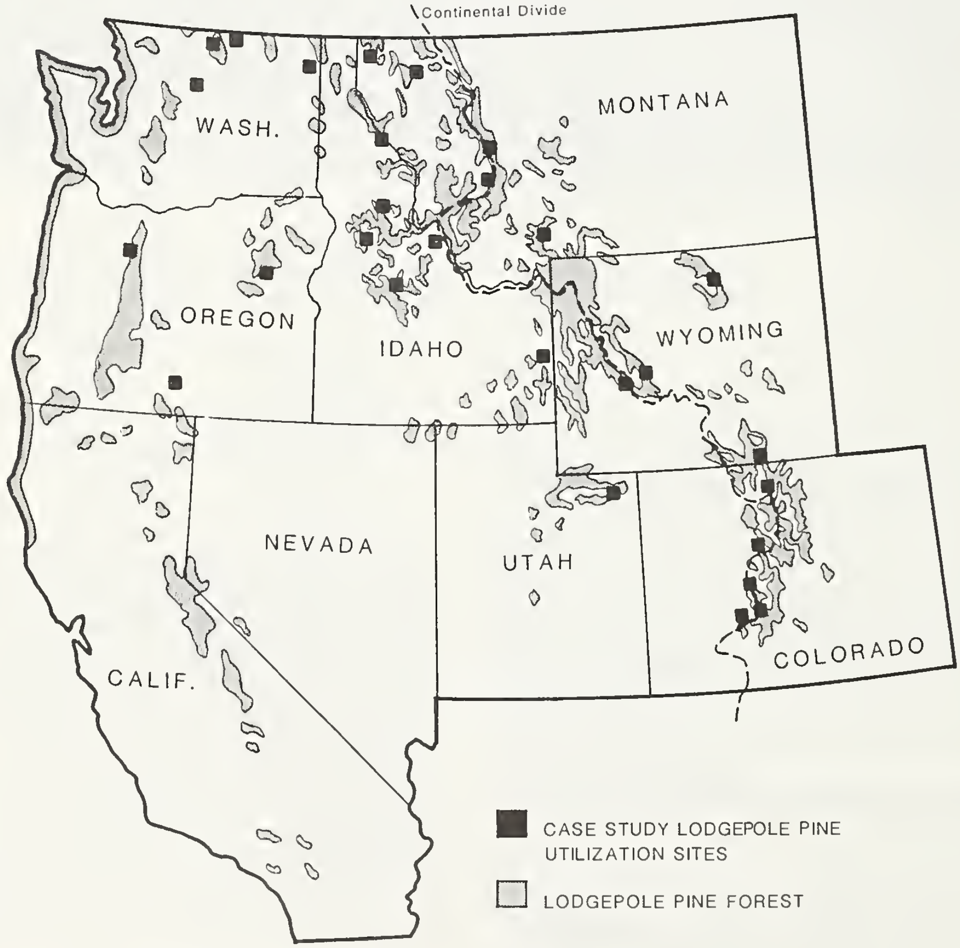

Figure 2-2—Distribution of lodgepole-pine-dominated forests in the United States. The black squares denote some typical lodgepole pine acreages on which the managers wish to improve values through stand replacement.

As explained in the introduction to this analysis, the proposed enterprise is principally concerned with only one of the 27 species of timber trees found in the State—lodgepole pine.

2-2 MONTANA LODGEPOLE PINE RESOURCE DATA

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is dominant on about 13 million acres of commercial forest land in the United States (fig. 2-2) containing 26.4 billion ft^3 of lodgepole **growing stock** and more than 71 billion bd ft of lodgepole sawtimber, mostly in Montana, Idaho, Wyoming, Colorado, and Oregon. Montana accounts for nearly half the volume of the species growing in the Rocky Mountains.

In Montana, lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) dominates on about 3.9 million acres of the State's 13.6 million acres of commercial forest land, with about 8.4 billion ft^3 of lodgepole pine growing stock and 18.7 billion bd ft of sawtimber (table 2-1). Approximately 33 percent of the softwood growing stock and 21 percent of the softwood sawtimber in the State is lodgepole pine (Green and others 1985).

Approximately 64 percent of the dry weight of needle-free above-ground biomass of lodgepole pine trees in Montana is in trees smaller than the 10-inch d.b.h. class (table 2-2).

Counties west of the Continental Divide have more lodgepole pine volume than those east of the Divide; greatest volumes of lodgepole **growing stock** (that is, stemwood volume from a 1-foot-high stump to a top diameter outside bark of 4 inches in all trees 5.0 inches in d.b.h. and larger) are found in Lincoln, Beaverhead, and Flathead Counties (fig. 2-3 and table 2-3). Concentration of growing-stock volume is greatest in Lincoln County.

Table 2-1—Net volume of lodgepole pine growing stock and sawtimber in Montana by ownership class, and acreage dominated by lodgepole, 1980 (Green and others 1985)

Ownership class	Growing stock[1]	Sawtimber[2]	Lodgepole-dominated commercial forest area
	Million ft^3	*Million bd ft, International 1/4-inch scale*	*Thousand acres*
National Forest	6,660.6	15,094.1	3,100.0
Other public	280.9	634.3	114.3
Forest industry	641.4	1,098.3	306.7
Farmers and other private	787.5	1,842.2	344.5
Total	8,370.4	18,668.9	3,865.5

[1]Growing stock is comprised of all trees 5 inches in d.b.h. and larger; the volume is for stemwood only from a 1-foot stump height to a 4-inch diameter top measured outside bark.
[2]Sawtimber is defined as trees 9 inches in d.b.h. and larger; the volume is for stemwood from a 1-foot stump height to a 7-inch top diameter measured outside bark.

Table 2-2—Dry weight of lodgepole pine trees, by tree component and diameter class—Montana (Van Hooser and Chojnacky 1983)

D.b.h. class	Bole[1]	Top[1]	Total
Inches	*- - - - - - Thousand tons, ovendry basis - - - - - -*		
[2]2	0	6,509	6,509
[2]4	0	21,301	21,301
6	30,654	16,883	47,537
8	35,351	9,120	44,471
10	25,842	6,248	32,090
12	15,864	3,893	19,757
14	7,485	1,669	9,154
16	3,129	637	3,766
18	1,123	225	1,348
20+	795	154	949
Total	120,243	66,639	186,882

[1]Trees 5 inches and larger in d.b.h.: Bole weight = ovendry weight of wood and bark from a 1-foot stump height to a 4-inch top diameter, outside bark. Top weight = ovendry weight of wood and bark from a 4-inch diameter (inside bark) to apical tip, plus branch material down to 1/4-inch diameter.
[2]Trees less than 5 inches in d.b.h.: Total ovendry weight of wood and bark from a 1-foot stump height to the apical tip, plus branch material down to 1/4-inch diameter (tabulated under "Top").

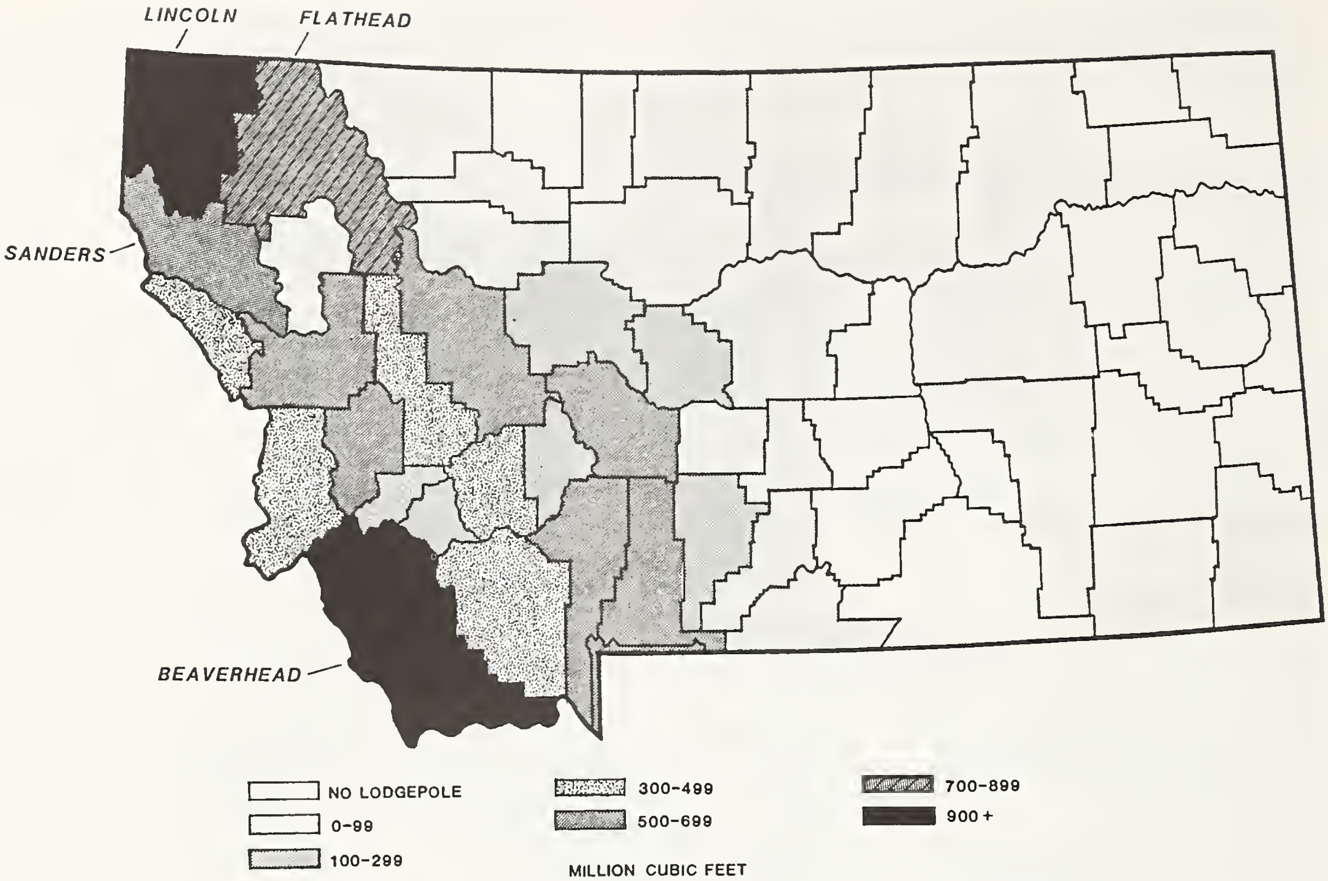

Figure 2-3—Distribution of lodgepole pine volume in Montana counties. Volume data (million cubic feet) are for stemwood in growing stock (trees 5 inches in d.b.h. and larger) from a 1-foot-high stump to a 4-inch top diameter measured outside bark. (Data from the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT.)

Table 2-3—Volume[1] of lodgepole pine growing stock, by Montana county, on commercial timberland administered by the Forest Service in the National Forest System, and administered by others (the State of Montana and other public agencies, industry, and private owners)

County	Forest Service	Other	Total
	- - - - - - - - - - - - - - - -	*Thousand ft³* - - - - - - - - - - - - - -	
Beaverhead	895,522.4	47,504.9	943,027.3
Big Horn	0	0	0
Blaine	0	2,999.3	2,999.3
Broadwater	109,575.0	5,182.6	114,757.6
Carbon	36,376.9	2,054.5	38,431.4
Carter	10,028.3	0	10,028.3
Cascade	163,874.5	28,640.4	192,514.9
Choteau	18,744.7	7,081.1	25,825.8
Custer	0	0	0
Daniels	0	0	0
Dawson	0	0	0
Deer Lodge	110,024.6	56,456.6	166,481.2
Fallon	0	0	0
Fergus	83,916.9	13,838.1	97,755.0
Flathead	474,689.0	248,676.5	723,365.5
Gallatin	472,255.1	96,054.7	568,309.8
Garfield	0	4,241.3	4,241.3
Glacier	12,658.9	1,980.0	14,638.9
Golden Valley	16,153.5	1,206.2	17,359.7
Granite	585,048.7	68,759.6	653,808.3
Hill	0	1,530.7	1,530.7
Jefferson	393,684.9	11,042.9	404,727.8
Judith Basin	255,524.3	1,712.0	257,236.3
Lake	49,912.5	45,409.9	95,322.4
Lewis and Clark	510,186.9	61,763.6	571,950.5
Liberty	0	816.6	816.6
Lincoln	999,922.8	185,793.9	1,185,716.7
McCone	0	0	0
Madison	389,018.2	84,998.9	474,017.1
Meagher	419,481.8	95,262.1	514,743.9
Mineral	393,425.6	42,663.2	436,088.8
Missoula	310,344.0	242,655.3	552,999.3
Musselshell	0	0	0
Park	485,074.7	63,766.7	548,841.4
Petroleum	0	0	0
Phillips	0	1,732.5	1,732.5
Pondera	63,907.8	1,364.0	65,271.8
Powder River	16,630.6	0	16,630.6
Powell	316,508.9	134,730.6	451,239.5
Prairie	0	0	0
Ravalli	319,556.5	12,225.8	331,782.3
Richland	0	0	0
Roosevelt	0	0	0
Rosebud	3,337.4	0	3,337.4
Sanders	550,969.4	91,837.0	642,806.4
Sheridan	0	0	0
Silver Bow	169,722.1	32,507.1	202,229.2
Stillwater	21,131.0	1,566.6	22,697.6
Sweet Grass	133,697.0	6,613.6	140,310.6
Teton	90,778.5	3,188.5	93,967.0
Tooele	0	0	0
Treasure	0	0	0
Valley	0	56.5	56.5
Wheatland	32,473.7	1,333.7	33,807.4
Wibaux	0	0	0
Yellowstone	0	0	0

[1]Stemwood in live lodgepole pine trees 5 inches in d.b.h. and larger from a 1-foot-high stump to a 4-inch top diameter measured outside bark. Data, based on survey information collected from 1966 through 1980, are from a special tabulation compiled by the Forest Survey Research Work Unit, Intermountain Research Station, Ogden, UT.

Numbers of lodgepole pine trees, by diameter class, in each Montana county where lodgepole pine is found—together with stemwood cubic volume in growing stock—are tabulated in appendix I. As previously noted, and as shown by appendix I, numbers of trees and stemwood volumes in growing stock are greatest on land administered by the National Forest System. Study of figure 2-3 and appendix I, together with extended conversations with resource analysts of the Forest Service's Intermountain Research Station, and with managers of lodgepole pine lands administered by the National Forest System, strongly suggest that the greatest concentration of available lodgepole pine in sub-sawlog and marginal sawlog size classes is in Lincoln County, together with adjoining northern Sanders County and western Flathead County.

2-3 LODGEPOLE PINE RESOURCE IN LINCOLN, FLATHEAD, AND SANDERS COUNTIES

A plant centrally located in Lincoln County might draw lodgepole pine from throughout the county plus western Flathead County and northern Sanders County (fig. 2-3). The lodgepole pine resource in these three counties can be assessed in terms of acreages, numbers of trees, and stemwood cubic volume or weight.

Acreage on Which Lodgepole Pine Predominates

Of the 3.9 million acres in Montana's commercial timberlands on which lodgepole pine dominates, about one-third (1.3 million acres) are in Lincoln, Flathead, and Sanders Counties.

Acreage of lodgepole pine forest type within the commercial timberlands of Flathead, Lincoln, and Sanders Counties can be classified according to ownership. Most is administered by the National Forest System, but a significant proportion of the lodgepole pine forest type within these three counties has other ownerships, as follows (data from a special tabulation compiled from 1977 information by the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT):

Ownership status	Acres	Proportion of non-National Forest ownerships
		- - Percent - -
Other public (not National Forest)	46,759	17.3
Forest industries	164,437	61.0
Farmer and other private	58,600	21.7
Total	269,796	100.0

County acreage within the National Forests of commercial timberlands in lodgepole pine type cannot be readily derived from available survey data. It can be approximated, however, by utilizing the data in table 2-7 (see p. 14) to conclude that in the three-county area, 79.4 percent of the lodgepole pine volume is on lands administered by the National Forests and 20.6 percent is on lands administered by other owners as defined in the preceding tabulation.

From these proportions it can be inferred that National Forest area of lodgepole pine type classified as commercial timberland totals about 1,039,893 acres within the three-county area. These data suggest that, with all ownerships considered, lodgepole pine dominates on 1,309,689 acres of the commercial timberland in the three-county area.

Numbers of Lodgepole Pine Trees

It is useful to know something about the numbers of lodgepole pine trees growing in the three counties and their distribution by diameter class. Excluding the 2-inch class (1.0 to 2.9 inches), which seems too small for utilization, the 4- through 6-inch diameter classes (that is, trees 3.0 through 6.9 inches in d.b.h.) comprise close to three-quarters of the remaining stems, as follows (table 2-4):

County	Total stems in the 4- through 30-inch diameter classes	Stems in the 4- through 6-inch diameter classes	
	Number	*Number*	*Percent*
Flathead	183,157,517	139,711,604	76.3
Lincoln	265,196,954	193,180,112	72.8
Sanders	125,913,469	86,986,929	69.1

With the 2-inch class (1.0 through 2.9 inches in d.b.h.) excluded, trees 8.9 inches in d.b.h. and smaller comprise 90 percent of all remaining lodgepole stems in these three counties (table 2-4).

While not specific to lodgepole pines from Lincoln, Flathead, and Sanders Counties, the data in table 2-5 are useful in visualizing the dimensions and weights of trees 3, 6, and 9 inches in d.b.h. These data represent average values for all lodgepole pines (var. *latifolia*) in North America. The weights of all above-stump tree portions (including foliage) averaged as follows (Koch 1987):

D.b.h.	Average weight of all tree parts above 6-inch-high stump	
	Green	Ovendry
Inches	*- - - - - Pounds - - - - -*	
3	54	28
6	334	171
9	875	453

In such trees 3, 6, and 9 inches in d.b.h., stemwood from 6-inch-high stump to apical tip represents 72 to 77 percent of the aboveground tree weight, stembark 7 to 11 percent, foliage-free branches 7 to 10 percent, and foliage and cones 8 to 11 percent (table 2-6).

Table 2-4—Number of live lodgepole pine trees on commercial timberland in three Montana counties, by diameter class[1] and administrative class

Diameter class	National Forests	Other[2]	Total
Inches	*Number of trees*		
	Flathead County		
2	35,721,959	33,126,047	68,848,006
4	52,731,730	34,974,566	87,706,296
6	34,475,806	17,529,502	52,005,308
8	18,455,405	7,997,966	26,453,371
10	7,031,519	3,260,056	10,291,575
12	3,133,559	1,011,455	4,145,014
14	1,402,830	442,101	1,844,931
16	467,798	71,333	539,131
18	127,204	12,343	139,547
20	20,018	5,014	25,032
22	4,783	864	5,647
24	256	1,409	1,665
Total	153,572,867	98,432,656	252,005,523
	Lincoln County		
2	32,920,429	27,745,757	60,666,186
4	78,215,244	28,002,686	106,217,930
6	72,408,716	14,553,466	86,962,182
8	38,097,171	6,211,449	44,308,620
10	15,899,375	2,294,163	18,193,538
12	6,060,588	602,682	6,663,270
14	1,765,928	269,305	2,035,233
16	523,057	48,443	571,500
18	149,023	11,328	160,351
20	64,104	3,109	67,213
22	15,732	943	16,675
24	0	432	432
26	0	0	0
28	10	0	10
Total	246,119,377	79,743,763	325,863,140
	Sanders County		
2	15,931,695	4,911,418	20,843,113
4	38,800,363	3,596,967	42,397,330
6	39,815,018	4,774,581	44,589,599
8	20,755,188	3,404,108	24,159,296
10	8,277,911	1,170,727	9,448,638
12	3,294,347	453,438	3,747,785
14	927,548	165,489	1,093,037
16	310,115	40,462	350,577
18	67,109	6,463	73,572
20	25,136	14,384	39,520
22	7,253	3,939	11,192
24	2,923	0	2,923
Total	128,214,606	18,541,976	146,756,582

[1]Diameter classes (measured at breast height, outside bark) span 1.9 inches; for example, the 4-inch class spans from 3.0 to 4.9 inches. Data, based on survey information collected from 1966 to 1980, are from a special tabulation compiled by the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT.
[2]State and other public, forest industry, and private ownerships.

Table 2-5—Some useful average dimensions and weights of lodgepole pine trees (var. *latifolia*) of three diameters[1]

Property	Tree d.b.h., inches 3	6	9
Height to 1-inch diameter outside bark, feet	26.3	48.2	60.0
Height to 2-inch diameter inside bark, feet	16.5	39.1	52.9
Height to base of live crown, feet	16.5	28.9	35.6
Diameter inside bark at base of crown, inches	2.0	3.9	5.8
Average branch diameter (near stem), inch	.35	.51	.75
Stemwood data; stump top to apical tip			
Volume, ft³	.75	4.95	13.33
Ovendry weight, lb	20.2	130.4	339.7
Ovendry weight /ft³ of green volume, lb	26.9	26.3	25.5
Stemwood volume within live crown, percent of total stemwood volume to apical tip		26.5	
Stemwood taper inside bark, inches/100 inches			
From 6-inch-stump to live-crown base	.63	.78	1.05
From base of crown to apical tip	1.31	1.59	1.85

[1]These data, summarized from Koch (1987), are averages for trees 3, 6, and 9 inches in d.b.h. collected throughout the major range of var. *latifolia* in North America; that is, from 40 to 60 degrees latitude.

Table 2-6—Average weight proportions of aboveground tree components of lodgepole pine (var. *latifolia*) of three diameters, from 6-inch-high stump level to apical tip[1]

Tree component and moisture basis	Tree d.b.h., inches 3	6	9
	Percent		
Stemwood			
Green	71.7	76.9	76.3
Ovendry	72.6	76.3	75.1
Stembark			
Green	11.0	7.8	6.5
Ovendry	10.1	7.8	6.8
Dead branches			
Green	1.3	1.4	1.5
Ovendry	2.1	2.1	2.4
Live branches (wood + bark)			
Green	5.4	6.0	8.0
Ovendry	5.3	6.0	7.9
Foliage and cones			
Green	10.6	7.9	7.7
Ovendry	9.9	7.8	7.8
Total			
Green	100.0	100.0	100.0
Ovendry	100.0	100.0	100.0

[1]These data, summarized from Koch (1987), are averages for trees 3, 6, and 9 inches in d.b.h. collected throughout the major range of var. *latifolia* in North America; that is, from 40 to 60 degrees latitude.

Cubic Volume of Lodgepole Pine Stemwood

In addition to knowledge of numbers of trees, it is useful to know something about the distribution of stemwood volume by diameter class in the three counties. Volume data for trees less than 5 inches in d.b.h. are unavailable; for lodgepole pines 5 inches in d.b.h. and larger on **commercial timberland**, stemwood volumes to a 4-inch top diameter outside bark can be summarized (from table 2-7) as follows:

County	National Forests	Other	Total
	M ft³ of stemwood		
Flathead	474,689.0	248,676.5	723,365.5
Lincoln	999,922.8	185,793.9	1,185,716.7
Sanders	550,969.4	91,837.0	642,806.4
Total	2,025,581.2	526,307.4	2,551,888.6

Thus, 79.4 percent of the cubic volume of lodgepole pine stemwood on commercial timberlands in these three counties is on acres administered by the National Forest System, and 20.6 percent is on other lands, that is, on lands owned by other public agencies, forest industries, and farmers or other private owners.

Of these total stemwood volumes, those represented by trees 5.0 to 8.9 inches in d.b.h. comprise 55.9, 58.2, and 57.2 percent in Flathead, Lincoln, and Sanders Counties, respectively. In other words, most of the stemwood volume is in sub-sawlog-size trees.

Available Lodgepole Pine Resource

The foregoing discussion has outlined the total lodgepole pine resource in Lincoln, Flathead, and Sanders Counties. More pertinent to this study is estimation of the acreages and volumes of lodgepole pine that are in suitable diameter classes and are potentially available during the next 20 years—a timespan approximately matched to anticipated plant life and to silvicultural objectives of the managers of National Forests in the area.

Trees suitable for the proposed operation should be less than 75 road miles from the plant site, in stands dominated by lodgepole pine, on slopes less than 55 percent, and in diameter classes generally spanning 3.0 to 8.9 inches—that is, in sub-sawlog or marginal sawlog diameters. Although there are no major technical difficulties in converting larger trees to structural flakeboard, it is deemed desirable to concentrate on the smaller trees as there is presently no major commercial use for small trees. Resource data on dead lodgepole pine are included in the event that conversion processes appropriate for dead timber can be developed.

At the time scheduled for stand replacement (harvest), truck-haul roads should be in place adjacent to the acreages (within one-fourth mile), and downslope from them.

Data on such available lodgepole pine are most accurately aggregated by National Forest rather than county. Less accurate are estimates of the available lodgepole resource on State and private lands.

Table 2-7—Volume of stemwood to a 4-inch top diameter outside bark in live lodgepole pine trees on commercial timberland in three Montana counties, by diameter class[1] and administrative class

Diameter class	National Forests	Other[2]	Total
		Ft³	
		Flathead County	
6	95,401,804	86,386,743	181,788,547
8	150,105,600	72,196,886	222,302,486
10	99,527,189	49,226,542	148,753,731
12	65,245,116	22,774,798	88,019,914
14	39,780,877	13,785,327	53,566,204
16	16,840,447	3,139,477	19,979,924
18	6,101,630	676,127	6,777,757
20	1,172,549	315,449	1,487,998
22	484,571	68,758	553,329
24	29,195	106,412	135,607
Total	474,688,978	248,676,519	723,365,497
		Lincoln County	
6	233,006,937	70,952,311	303,959,248
8	330,286,633	55,568,651	385,855,284
10	229,091,836	34,103,404	263,195,240
12	125,348,313	13,554,824	138,903,137
14	46,975,408	8,512,013	55,487,421
16	21,265,463	2,179,469	23,444,932
18	8,588,889	619,923	9,208,812
20	4,354,396	195,601	4,549,997
22	1,002,952	75,075	1,078,027
24	0	32,653	32,653
26	0	0	0
28	1,944	0	1,944
Total	999,922,771	185,793,924	1,185,716,695
		Sanders County	
6	129,084,108	24,562,918	153,647,026
8	182,592,953	31,447,468	214,040,421
10	122,034,982	17,183,812	139,218,794
12	71,290,880	10,179,138	81,470,018
14	26,184,872	5,311,933	31,496,805
16	13,347,245	1,546,860	14,894,105
18	3,836,231	302,624	4,138,855
20	1,725,473	1,004,389	2,729,862
22	539,343	297,869	837,212
24	332,772	0	332,772
26	0	0	0
28	513	0	513
Total	550,969,372	91,837,011	642,806,383

[1]Diameter classes (measured at breast height, outside bark) span 1.9 inches; for example, the 6-inch class spans from 5.0 to 6.9 inches. Data, based on survey information collected from 1966 to 1980, are from a special tabulation compiled by the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT.

[2]State and other public, forest industries, and private ownerships.

Kootenai National Forest—The major available resource satisfying the requirements outlined under the foregoing heading lies within the Kootenai National Forest (table 2-8).

Excluding acreage dominated by live lodgepole pine sawtimber, and considering only stagnated, marginal sawlog, and dead sawtimber stands within 75 road miles of Libby on slopes less than 56 percent, more than half of the resource is in marginal sawlog stands, as follows (table 2-8; see table footnotes for stand definitions):

Stand type	Area	Stemwood weight, ovendry
	Acres	*Tons*
Stagnated	13,196	504,624
Marginal sawlog	29,312	1,192,686
Dead sawtimber	13,031	423,105
Total	55,539	2,120,415

About 60 percent of these 55,539 acres are roaded (as of 1987); that is, a road passes within one-fourth mile of the stands, as follows (table 2-8):

Stand type	Roaded	Unroaded
	Acres	*Acres*
Stagnated	9,418	7,405
Marginal sawlog	15,702	10,812
Dead sawtimber	8,160	4,042
Total	33,280	22,259

When acreages of all three of these lodgepole stand types on the Kootenai National Forest are summed, more than two-thirds of the acreage is within 40 road miles of Libby (table 2-9).

Table 2-8—Acres and ovendry tons[1] of lodgepole pine (stagnated, marginal sawlog, and dead sawtimber) available during the next 20 years from the Kootenai National Forest, related to slope, road distance from Libby, and road access (data from Kootenai National Forest, 1987)

Road status and road distance from Libby	Slope 0-20%	Slope 21-40%	Slope 41-55%	Totals	Average tons/acre
		Stagnated			
Roaded[2]					
<20 miles					23.6
Acres	33	606	0	639	
Tons	1,099	13,985	0	15,084	
21-40 miles					30.3
Acres	851	2,654	594	4,099	
Tons	21,926	85,371	16,885	124,182	
41-60 miles					32.1
Acres	959	693	91	1,743	
Tons	31,350	21,293	3,365	56,008	
61-75 miles					26.7
Acres	997	1,762	178	2,937	
Tons	23,284	45,238	7,090	75,612	
Totals					28.8
Acres	2,840	5,715	863	9,418	
Tons	77,659	165,887	27,340	270,886	
Unroaded					
<20 miles					28.0
Acres	49	221	610	880	
Tons	1,194	7,367	16,032	24,593	
21-40 miles					30.1
Acres	524	2,381	461	3,366	
Tons	10,751	78,670	11,749	101,170	
41-60 miles					34.6
Acres	573	851	614	2,038	
Tons	20,742	24,108	25,583	70,433	
61-75 miles					29.9
Acres	319	573	229	1,121	
Tons	7,230	17,090	9,153	33,473	
Totals					31.0
Acres	1,465	4,026	1,914	7,405	
Tons	39,917	127,235	62,517	229,669	
TOTALS (Stagnated)					29.8
Acres	4,305	9,741	2,777	16,823	
Tons	117,576	293,122	89,857	500,555	

(con.)

Table 2-8 (Con.)

Road status and road distance from Libby	Slope 0-20%	21-40%	41-55%	Totals	Average tons/acre
		Marginal sawlog timber			
Roaded[2]					
<20 miles					50.2
Acres	282	1,571	144	1,997	
Tons	9,377	88,632	2,149	100,158	
21-40 miles					33.5
Acres	1,475	3,287	2,602	7,364	
Tons	50,994	117,800	77,577	246,371	
41-60 miles					37.9
Acres	951	1,434	211	2,596	
Tons	33,187	57,094	8,101	98,382	
61-75 miles					38.1
Acres	1,703	2,008	34	3,745	
Tons	65,500	76,273	1,079	142,852	
Totals					37.4
Acres	4,411	8,300	2,991	15,702	
Tons	159,058	339,799	88,906	587,763	
Unroaded					
<20 miles					28.1
Acres	125	348	4,061	4,534	
Tons	4,247	11,600	111,363	127,210	
21-40 miles					37.5
Acres	311	2,211	1,562	4,084	
Tons	12,488	90,952	49,660	153,100	
41-60 miles					34.8
Acres	775	690	468	1,933	
Tons	30,912	18,481	17,908	67,301	
61-75 miles					35.1
Acres	0	244	17	261	
Tons	0	8,397	763	9,160	
Totals					33.0
Acres	1,211	3,493	6,108	10,812	
Tons	47,647	129,430	179,694	356,771	
TOTALS (Marginal sawlog)				35.6	
Acres	5,622	11,793	9,099	26,514	
Tons	206,705	469,229	268,600	944,534	
		Dead sawtimber			
Roaded[2]					
<20 miles					52.9
Acres	338	742	52	1,132	
Tons	18,633	37,576	3,633	59,842	
21-40 miles					56.0
Acres	2,194	3,912	519	6,625	
Tons	120,951	218,169	31,605	370,725	
41-60 miles					55.6
Acres	223	180	0	403	
Tons	11,435	10,962	0	22,397	
61-75 miles					—
Acres	0	0	0	0	
Tons	0	0	0	0	
Totals					55.5
Acres	2,755	4,834	571	8,160	
Tons	151,019	266,707	35,238	452,964	
Unroaded					
<20 miles					48.8
Acres	0	708	420	1,128	
Tons	0	34,038	21,000	55,038	

(con.)

Table 2-8 (Con.)

Road status and road distance from Libby	Slope 0-20%	21-40%	41-55%	Totals	Average tons/acre
21-40 miles					59.8
Acres	514	1,696	164	2,374	
Tons	29,324	103,282	8,410	141,016	
41-60 miles					48.7
Acres	0	540	0	540	
Tons	0	26,308	0	26,308	
61-75 miles					—
Acres	0	0	0	0	
Tons	0	0	0	0	
Totals					55.0
Acres	514	2,944	584	4,042	
Tons	29,324	163,628	29,410	222,362	
TOTALS (Dead sawtimber)					55.4
Acres	3,269	7,778	1,155	12,202	
Tons	180,343	430,335	64,648	675,326	
	Stagnated, marginal sawlog, and dead sawtimber aggregated				
Roaded[2]					
<20 miles					46.5
Acres	653	2,919	196	3,768	
Tons	29,109	140,193	5,782	175,084	
21-40 miles					41.0
Acres	4,520	9,853	3,715	18,088	
Tons	193,871	421,340	126,067	741,278	
41-60 miles					37.3
Acres	2,133	2,307	302	4,742	
Tons	75,972	89,349	11,466	176,787	
61-75 miles					32.7
Acres	2,700	3,770	212	6,682	
Tons	88,784	121,511	8,169	218,464	
Totals					38.8
Acres	10,006	18,849	4,425	33,280	
Tons	387,736	772,393	151,484	1,311,613	
Unroaded					
<20 miles					31.6
Acres	174	1,277	5,091	6,542	
Tons	5,441	53,005	148,395	206,841	
21-40 miles					40.2
Acres	1,349	6,288	2,187	9,824	
Tons	52,563	272,904	69,819	395,286	
41-60 miles					36.4
Acres	1,348	2,081	1,082	4,511	
Tons	51,654	68,897	43,491	164,042	
61-75 miles					30.9
Acres	319	817	246	1,382	
Tons	7,230	25,487	9,916	42,633	
Totals					36.3
Acres	3,190	10,463	8,606	22,259	
Tons	116,888	420,293	271,621	808,802	
TOTALS (Stagnated, marginal and dead)					38.2
Acres	13,196	29,312	13,031	55,539	
Tons	504,624	1,192,686	423,105	2,120,415	

[1]Derived from cubic-foot data and converted at 25 pounds of ovendry stemwood per cubic foot of green stemwood volume. Tonnage data for all three stand classes include only those trees 5 inches in d.b.h. and larger to a top diameter of 4 inches measured inside bark.

Stagnated stands are defined as having less than 2,000 bd ft per acre, Scribner scale.

Marginal sawlog stands have less than 5,000 bd ft, but more than 2,000 bd ft per acre, Scribner scale.

Dead sawtimber stands are defined as stands with more than 5,000 bd ft per acre, Scribner scale, in which trees are dead or infested with pine bark beetle and expected to die within 2 years.

[2]Within one-fourth mile of a road; these roads are not necessarily downslope from the acreages, but most are.

Table 2-9—Acres and percentage of acres dominated by lodgepole pine on the Kootenai National Forest that have stagnated, marginal sawlog, and dead sawtimber on slopes less than 56 percent, and that are within 75 road miles of Libby (data from Kootenai National Forest, 1987)

Distance from Libby	Stagnated	Marginal sawlog	Dead sawtimber	Total
<20 miles				
Acres	1,519	6,531	2,260	10,310
Percent	9.0	24.6	18.5	18.5
21-40 miles				
Acres	7,465	11,448	8,999	27,912
Percent	44.4	43.2	73.8	50.3
41-60 miles				
Acres	3,781	4,529	943	9,253
Percent	22.5	17.1	7.7	16.7
61-75 miles				
Acres	4,058	4,006	0	8,064
Percent	24.1	15.1	0	14.5
Total				
Acres	16,823	26,514	12,202	55,539
Percent	100.0	100.0	100.0	100.0

Only 13,031 acres (23 percent) of the total of 55,539 acres in these three stand types on slopes less than 56 percent are on terrain having slopes of 41 to 55 percent; 29,312 acres (53 percent) have slopes of 21 to 40 percent; and 13,196 acres (24 percent) are on slopes of 20 percent or less (table 2-8).

Western Portion of Flathead National Forest—Within 75 miles of the Libby-Troy area, the Flathead National Forest has 9,648 acres of similar lodgepole pine timber totaling 266,258 tons (ovendry basis) of stemwood (table 2-10). On average, these commercial timberlands have about 27.6 tons of stemwood per acre in trees 5 inches and larger in d.b.h. to a 4-inch top diameter measured inside bark. About 20 percent of the acres are within one-fourth mile of a road. Slightly more than half (54.3 percent) of the tonnage is in dead sawtimber stands, 41.5 percent in marginal sawtimber stands, and only 4.2 percent in stagnated sub-sawlog stands.

Northeastern Portion of Idaho Panhandle National Forests—The Bonners Ferry Ranger District of the Idaho Panhandle National Forests has, within 75 road miles of Libby-Troy, areas of similar lodgepole pine (9,700 acres) about equal to that on the Flathead National Forest. Because the threshold dimensions of trees included in the Idaho tabulation are larger than those in the Montana tabulation, tonnages are difficult to compare (see footnote 1 of table 2-10); if the Flathead criteria were applied to the Panhandle acreage, however, tonnages would probably be about equal. About 27 percent of the Idaho area is within one-fourth mile of a road. Most of the acreage (80 percent) is in marginal sawlog stands, and the balance is evenly divided betwen stagnated and dead timber (table 2-10).

State and Private Lands—As previously noted, outside of the National Forests there are about 269,796 acres of lodgepole pine forest type within the commercial timberlands of Flathead, Lincoln, and Sanders Counties. Of these non-National Forest acres, 17.3 percent are publicly owned, 61.0 percent are forest-industry owned, and 21.7 percent are owned by farmers and other private people.

All lodgepole volume in all types of stands—including sawtimber—on State and private lands in these counties totals 526,307,400 ft^3 of stemwood in trees 5 inches in d.b.h. and larger to a 4-inch top measured outside bark (table 2-3); this amounts to 6,578,842 tons of stemwood, ovendry basis.

Summary of Available Resource

The National Forest available lodgepole pine resource within 75 miles of Libby-Troy on slopes of 55 percent or less in stagnated, marginal, and dead stands can be summarized as follows:

National Forest	Acres	Stemwood in trees 5 inches in d.b.h. and larger to a 4-inch top inside bark
		Tons, ovendry
Flathead	9,648	266,258
Kootenai	55,539	2,120,415
Idaho Panhandle	9,700	266,258
Total	74,887	2,652,931

These data suggest that—averaging the three stand types—there are about 35.4 tons per acre of stemwood (ovendry) in trees 5 inches in d.b.h. and larger to a 4-inch top.

Additionally, State and private lodgepole pine lands in the three-county area (not necessarily available or within 75 miles of Libby-Troy, or on slopes of 55 percent or less) total about 269,796 acres, with a total stemwood weight (ovendry) of 6,578,842 tons. This tonnage includes live lodgepole sawtimber as well as the three less valuable classes of stands considered on the National Forests. Assuming that 5 percent of this acreage (that is, 13,490 acres) and this tonnage (that is, 328,942 tons) are economically available to a plant in the Libby-Troy area, then the total available resource in trees 5 inches d.b.h. and larger to a 4-inch top would be about 101,867 acres and 3,310,815 tons of stemwood (ovendry basis).

While somewhat more distant, there are similar stands—totaling perhaps 17,500 acres—that will be available over the next 20 years on the west end of the Lolo National Forest. The lodgepole pine stemwood in these stands might average about 35 tons per acre (ovendry basis), for a total of 612,500 tons to a 4-inch top inside bark.

Most of the roundwood (doweled) products envisioned for production use only those portions of lodgepole pine trees too small to be inventoried in all of the previous compilations; that is, those portions with a minimum top diameter inside bark of as little as $2^1/4$ inches, and a maximum butt diameter of perhaps $4^1/2$ inches inside bark. It seems reasonable to assume that these noninventoried tree portions total near 20 percent of the weight of the inventoried portions in the lodgepole stands under consideration.

All of these acres and tonnages, identified as available during the next 20 years, can be aggregated as follows:

Table 2-10—Acres and ovendry tons[1] of lodgepole pine in stagnated, marginal sawlog, and dead sawtimber stands available from the Flathead National Forest and Idaho Panhandle National Forests during the next 20 years within 75 road miles of Libby-Troy from slopes of 55 percent or less, related to road access (data from the Flathead and Idaho Panhandle National Forests, 1987)

Road status[2] and statistic	Subsawlog stagnated[3]	Marginal sawlog[4]	Dead sawtimber[5]	Totals	Average tons/acre
		Flathead National Forest			
Roaded					27.6
Acres	214	1,072	643	1,929	
Tons	2,220	22,083	28,935	53,238	
Unroaded					27.6
Acres	858	4,288	2,573	7,719	
Tons	8,902	88,333	115,785	213,020	
Total					27.6
Acres	1,072	5,360	3,216	9,648	
Tons	11,122	110,416	144,720	266,258	
Tons/acre	10.4	20.6	45.0	27.6	
	Idaho Panhandle National Forest (Bonners Ferry Ranger District)				
Roaded					13.5
Acres	1,000	1,600	0	2,600	
Tons	5,000	30,000	0	35,000	
Unroaded					17.7
Acres	0	6,100	1,000	7,100	
Tons	0	114,375	11,250	125,625	
Total					16.6
Acres	1,000	7,700	1,000	9,700	
Tons	5,000	144,375	11,250	160,625	
Tons/acre	5.0	18.8	11.3	16.6	

[1]Tonnages are derived from cubic-foot data and converted at 25 pounds of ovendry stemood per cubic foot of stemwood volume. Tabulated Flathead National Forest data in all three stand classes are for trees 5 inches and larger in d.b.h. to a top diameter of 4 inches measured inside bark. Tabulated Idaho Panhandle data, however, includes trees defined as follows:

Stagnated: trees 6 inches in d.b.h. and larger to a 5-inch top outside bark.

Marginal and dead sawtimber: trees 9 inches in d.b.h. and larger to a 5-inch top outside bark.

[2]Roaded acreages are defined as those within one-fourth mile of a haul road; these roads are not necesarily downslope from the acreages, but most are.

[3]Subsawlog stagnated stands have less than 2,000 bd ft per acre, Scribner scale.

[4]Marginal sawlog stands have less than 5,000 bd ft, but more than 2,000 bd ft per acre, Scribner scale.

[5]Dead sawtimber stands are defined by the Flathead National Forest as stands with more than 5,000 bd ft per acre, Scribner scale, in which trees are dead or infested with mountain pine beetle and expected to die within 2 years. The Idaho Panhandle National Forests define dead sawtimber stands as having more than 60 merchantable—but dead—stems per acre.

Source	Available acres	Available weight of stemwood in trees 3 inches and larger in d.b.h. to a top diameter of 2¼ inches inside bark
		Tons, ovendry
Flathead NF	9,648	319,510
Kootenai NF	55,539	2,544,498
Panhandle NF	9,700	319,510
State and private	13,490	328,942
Lolo NF	17,500	735,000
Total	105,877	4,247,460

To be conservative, harvest from sub-sawlog-size and dead-timber stands in the Libby-Troy procurement area should be limited to perhaps 2,200,000 tons over the 20-year life of the proposed plant (110,000 tons, ovendry, annually), or 52 percent of the total just tabulated as available from these stand classes for which there is little or no demand. These tonnages of lodgepole pine tabulated as available (tables 2-8 and 2-10) are probably underestimated by about 7 percent because the data are based on a conversion factor of 25 pounds of ovendry stemwood per cubic foot of green stemwood volume; sampling in the Libby-Troy latitudinal zone suggests that a conversion factor of 26.8 pounds would be more realistic.

In assessing the adequacy of the raw material supply, it should also be recognized that trees of sawlog diameter—not only of lodgepole pine, but including other species—can be introduced into structural flakeboard without adverse effects. It is conservatively estimated that over 20 years of plant life, an additional 1,800,000 tons (90,000 tons, ovendry, annually) of such stemwood could be purchased at a cost somewhat less than the cost of harvesting sub-sawlog-size lodgepole pine.

In summary, the available wood resource in the Libby-Troy procurement area should be amply adequate for an annual plant consumption of stemwood totaling 200,000 tons, ovendry basis—110,000 tons of lodgepole pine not normally suitable for sawmill consumption, plus 90,000 tons of tree-length logs comprising a mixture of coniferous species, but including a major component of lodgepole pine—perhaps 50 percent.

2-4 SITE SELECTION

Selection of a plant site within the State of Montana was one of the conditions of this analysis. Beyond this proscription, site selection is most strongly influenced by location of the available wood supply, followed by need for rail transport of products to market. Additionally, the proposed plant should not be located where air pollution is currently a problem. Also, a stable workforce, equitable taxes, and availability of needed utilities are essential for the proposed plant.

Procurement Area

As previously discussed, in Montana the greatest concentration of available lodgepole pine suitable for the proposed multiproduct plant lies in Lincoln, Flathead, and Sanders Counties. To permit logging trucks to average three round trips per day—thereby avoiding excessive log transport costs—procurement-area radius should average 40 to 50 road miles and not exceed 75 road miles. Distribution of the lodgepole pine resource in northwestern Montana is such that a location in Lincoln County appears most central. Figure 2-4 shows the area of consideration and various features discussed in the following analysis.

Transport of Products to Market

The two major products of the proposed plant—structural flakeboard and fabricated joists—must be transported to distant markets primarily by rail. Some of the roundwood products, such as tree props, are customarily shipped to market by truck. The site selected must therefore be adjacent to a railroad and have ready access to major highways. Study of Montana's transport network (fig. 2-5) indicates that the plant—if it is to be in Lincoln County—must be sited along the Burlington Northern rail line. Because of limited level land unthreatened by the Kootenai River along the rail line east of Libby, potential plant sites are restricted to the ground adjoining the

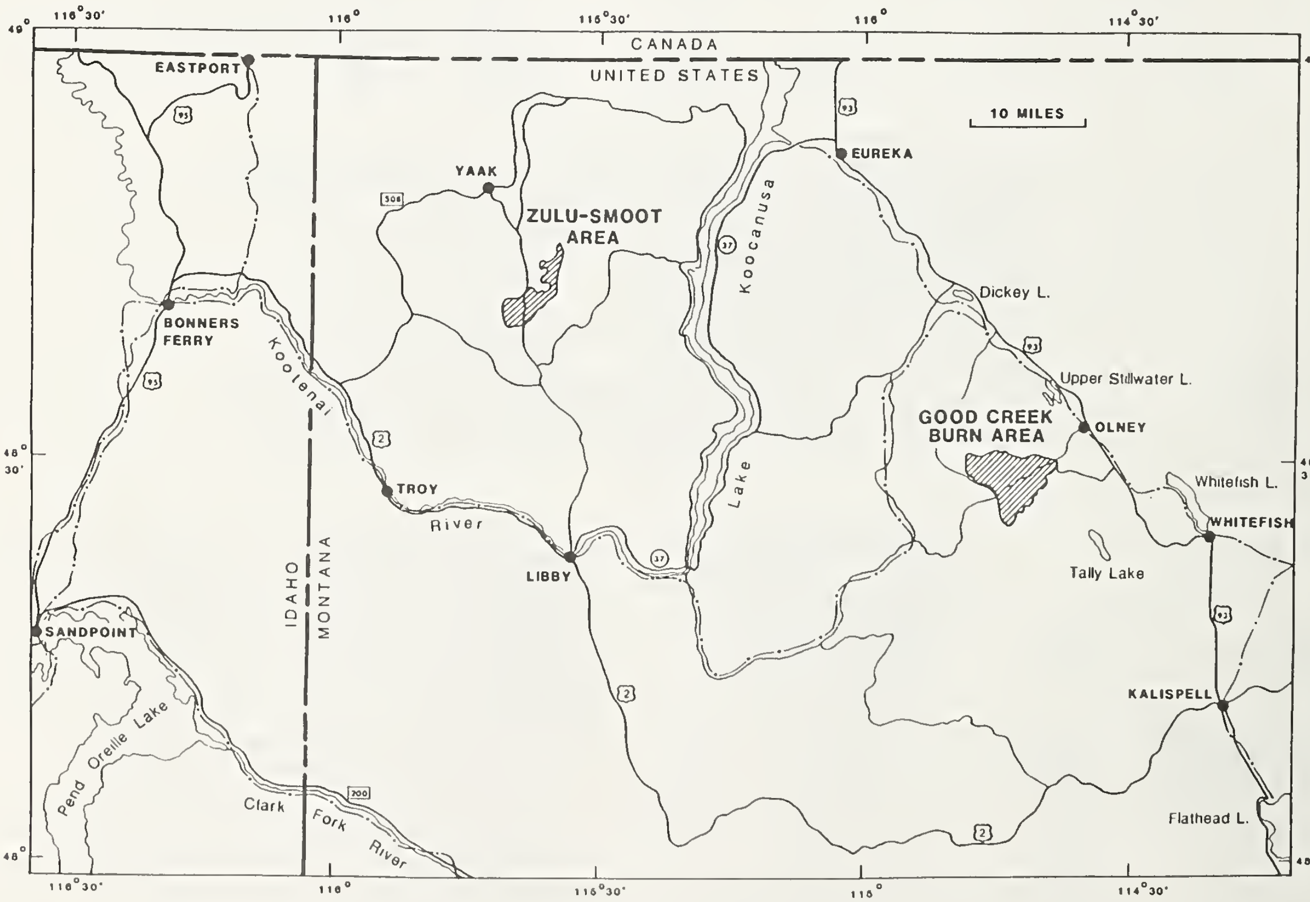

Figure 2-4—The Libby-Troy region of northwestern Montana. The procurement area contemplated has a radius of about 75 road miles from Libby-Troy, extending approximately from Bonners Ferry in the west, to near the Canadian border in the north, near Eureka in the northeast, Tally Lake vicinity in the east, and the map border in the south. The shaded areas are acreages of stagnated lodgepole pine that received special study in 1986.

MONTANA

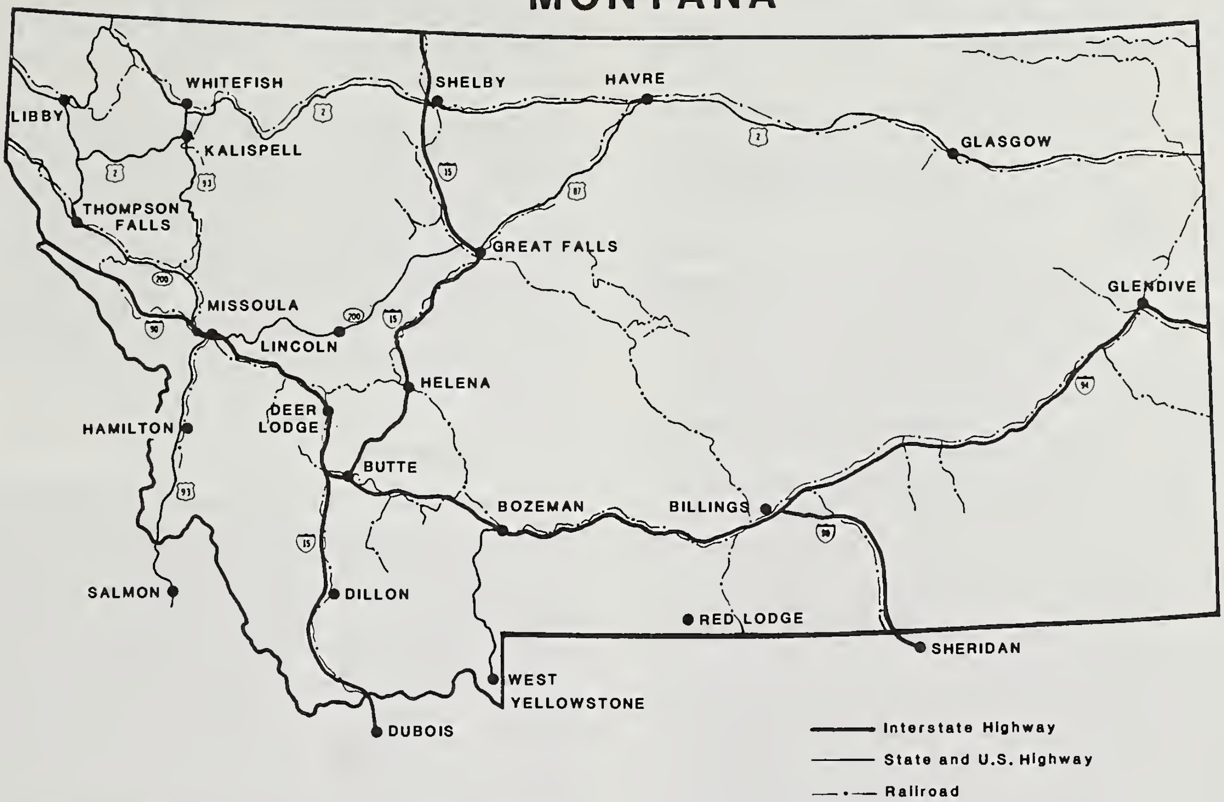

Figure 2-5—Railroads and principal highways in Montana.

railroad from the vicinity of Libby to the Idaho border. Moyie Springs, ID, 43 miles northwest of Libby, is a railhead on the Union Pacific line.

Other Considerations

Pollution Potential—Current levels of air pollution in the immediate vicinity of Libby suggest that if the plant is to be near Libby it should be 2 or 3 miles upstream to the east. Alternatively, the plant might be located adjacent to Troy, or 2 or 3 miles northwest of Troy along the Kootenai River.

Climate—Libby lies at 2,000 feet elevation, has a mean annual precipitation of 18.85 inches, mean annual snowfall of 55.6 inches, and average wind velocity of 2 mi/h. It is in an inversion area. Climate is less severe in Libby than in the rest of Montana, with mean daily maximum temperatures of 30 °F in January and 90 °F in July. Troy has an elevation of 1,889 feet, mean annual precipitation of 23.6 inches, mean annual snowfall of 47.3 inches, and average wind velocity of 5.3 mi/h.

Labor Supply in Procurement Area—Lincoln County has a total population of 18,160 (1980 census). Unemployment during 1986 averaged 11.5 percent of the county workforce; for the same period the entire State of Montana had an unemployment rate of 8.1 percent. The county seat of Libby is the largest community in the county, with 2,748 people within the town limits and 10,960 within a 4-mile radius. Troy has a population of 1,084 within the town limits and 4,200 including adjacent area. In 1986, sawmills in the area employed about 550 workers.

Forest Products Industry in the Vicinity—There is a major sawmill and plywood manufacturing complex located in Libby, but it is not presently designed to process sub-sawlog-size lodgepole pine. Three sizable sawmills manufacturing random-length dimension lumber are located near Eureka, but they are not designed for sub-sawlog-size lodgepole pine.

Two sizable mills manufacturing 2- by 4-inch studs are located near Bonners Ferry (the one at Moyie Springs draws considerable lodgepole pine sawtimber from the Yaak area); there is also a large stud mill at Olney, which cuts lodgepole pine almost exclusively. Also, there is a small sawmill located between Yaak and Troy. In January 1988, announcement was made of plans for a new sawmill in Libby to produce green lodgepole pine studs for shipment to Moyie Springs for drying and planing.

Manufacturers of roundwood include a post and pole operation near Bonners Ferry and a house log producer near Eureka. The nearest pulp mill is near Missoula, about 190 miles from Libby. A medium-size structural flakeboard plant utilizing lodgepole pine is located at Chilco, ID—about 125 miles from Libby.

Utilities—At any of the five identified potential plant sites adjacent to the railroad near Libby and Troy, water for plant operation appears to be available from the Kootenai River. Spent process water from the plant would likely have to be evaporated or settled from ponds, rather than returned to the river.

Pacific Power and Light Company has a power line adequate to serve the operation within one-fourth mile of a potential plant site a few miles east of Libby. Sites near Troy are out of this company's service area.

A potential plant site immediately adjacent to Troy could be served by Montana Light and Power—a subsidiary of Champion International, Inc.; adequacy of this power supply for the continuous operation contemplated is doubtful, however.

Northern Lights, Inc., also serves the Troy site and other sites downstream (northwest) of Troy. This company has a substation just east of Troy on the west side of the river and power lines running northwest; downstream from Troy they are on the north side of the Kootenai River. Northern Lights has available power adequate for the proposed operation and maintains a two-person crew staffing an Outlying Service Area in Troy.

Natural gas is unavailable at any of the potential sites in the Libby-Troy area.

A rail siding is in place at the potential site in Troy, but at other potential sites a rail siding would have to be constructed. Difficulties in accomplishing such siding construction along this main line of the Burlington Northern have yet to be assessed.

Property Tax Incentives—Under a local-option industrial tax incentive, new industrial properties pay significantly reduced property taxes during the first 3 years of operation, and somewhat reduced taxes for years 4 through 9 on a schedule under which the property is fully taxed by the tenth year.

Community Attitudes—The Lincoln County Development Council, headquartered in Libby, works actively to encourage industrial growth in the county. Residents in Libby and Troy appear to be supportive of new and existing forest-based industries in the area.

City Governments—Both Libby and Troy have mayor/council-type governments. Libby has a city zoning ordinance in effect, but Troy does not. Both communities are served by volunteer fire departments and ambulance services.

Medical Services—Libby has a 34-bed hospital, a 64-bed convalescent center, and a mental health center. In 1986 the Libby area had 10 doctors, six dentists, two veterinarians, three chiropractors, and two optometrists. Troy has a medical clinic staffed by one doctor. Additionally, there is one dentist and one chiropractor in the community.

Amenities—Recreational opportunities in the Libby-Troy area include access to the Kootenai National Forest and the Cabinet Mountain Wilderness Area. The Kootenai River is adjacent to both communities, and Lake Koocanusa is only a few miles east of Libby. Other major lakes in the area include Bull, Savage, Spar, and Kilbrennan.

The area provides excellent fishing and hunting opportunities, and community facilities include golf courses, tennis courts, bowling alleys, and city parks.

The Libby area has four elementary schools, one junior high school, one high school, three private schools, and a community college. The Troy area has four elementary schools, a junior high school, a high school, and one private school; the area is served by the Flathead Valley Community College extension program. Libby has 20 churches, and Troy has nine. Both communities have free county libraries.

Other—The State of Montana Job Service Office in Libby can assist in recruitment of workers for jobs described by the employer. In addition, the Montana Department of Labor and Industry has funds available for startup training programs and also for on-the-job training. Up to $41,000 is available for startup training needs for new employers. Typically during on-the-job training, the employer pays 50 percent of the wages, and the State pays 50 percent during the training period—which can extend up to 3 months.

Conclusions

The need to be on a railroad and centrally located in respect to an adequate timber resource suggests selection of a Lincoln County site in the Libby-Troy area (fig. 2-4). Air pollution potential in the area is a consideration in plant location, but it is believed that there are at least five potential sites available adjacent to the Burlington Northern railroad and the Kootenai River. These sites range in size from 40 to 200 acres. The Lincoln County Economic Development Council has additional descriptive data on these sites. For the purposes of this analysis, it is sufficient to conclude that a suitable site can be acquired in the Libby-Troy area.

Also available for consideration are three acreages owned by the State of Montana. These potential sites are near the confluence of the Kootenai and Fisher Rivers east of Libby and south of Lake Koocanusa (fig. 2-4). All have access to the Burlington Northern rail line, although one would require construction of a short spur line.

2-5 PROCUREMENT, HARVESTING, AND TRANSPORT PROCEDURES

Procurement

At the outset it should be understood that the major contemplated operation in the forest is a stand replacement, not a timber sale. That is, the company planning to utilize the biomass will—in a no-cost exchange for most of the biomass on each acre—agree to:

- Build the necessary minimum-quality, short, temporary access roads to perform the required clearcuts prescribed by the National Forests' long-range management plans. At least in the initial decade of the plan, these clearcuts will be made on land having slopes of 55 percent or less. It will be the responsibility of the land managers to construct the principal haul roads serving the areas.
- Shear (or saw-fell) and remove from the forest essentially all of the aboveground biomass of all trees of all species larger than 3 inches in d.b.h. (with the exception of some of the cone-bearing branches to favor regeneration). If the stand lacks sufficient viable seed, it will be the responsibility of the public land manager to supplement the seed by direct seeding at the appropriate time.

- Trample all stems 3 inches and less in d.b.h. This should result in less than 25 tons (ovendry basis) of slash on the ground. This slash will be neither piled nor burned, but simply be compacted by trampling and subsequent snowfall.
- Equip feller-bunchers and skidders with tracks designed to expose a maximum of mineral soil to favor natural regeneration. On areas where insufficient mineral soil was exposed because they were logged in deep snow, or for other reasons, it will be the responsibility of the land manager to roller chop—or otherwise adequately prepare the seedbed—according to prescription.
- To avoid unnecessary drain on the forest nutrient pool, restrict pile and burn operations to landings only, where slash may accumulate.

Harvesting

Steep-slope feller bunchers equipped with accumulators and shears or saws (fig. 2-6), each teamed with a forwarder (fig. 2-7) capable of operating on slopes up to 55 percent will comprise the primary harvesting equipment. For less steep ground, less expensive feller bunchers, each teamed with a pair of grapple skidders, will be used. In addition to felling, bunching, and forwarding (average of 2,000 feet for the forwarders and 700 feet for the skidders) about 900 trees per 8-hour day (an average maintained for 243 days out of the year), these vehicles should be able to effectively trample most of the small trees during all seasons, and expose mineral soil for seeding under all but deep-snow conditions. Trees forwarded or skidded to roadside will be loaded onto trucks (fig. 2-8) with a mobile grapple shared by each pair of feller bunchers.

Transport of Trees to Plant

Trees from most acreages will have small crowns and will be transported to the mill (fig. 2-8) with crowns attached. Stems from some stands will have such heavy crowns that they will require delimbing prior to transport, but this requirement will be unusual.

Alternatively, if biomass from branches proves in excess of needs for plant thermal energy (see page 70), at additonal cost all trees could be mechanically stroke-delimbed at landings prior to loading on trucks.

Trees will be offloaded by crane at the plant, stored in high decks, and water-sprayed in summer when risk of fungal stain is high.

Cost of Harvest and Transport

A cost analysis of harvest and transport operations (appendix II) indicates that whole trees (entire above-ground tree portions, including branches and foliage) can be harvested and loaded on log trucks for about $35 per ton (ovendry basis) of stemwood, assuming that bark, branches, and foliage bear no cost burden. This includes

Figure 2-6—Track-mounted steep-slope feller buncher equipped with self-leveling platform carrying a boom-mounted shear (or saw) that can accumulate severed stems preparatory to depositing them in a bunch. (Photo from Koch 1987.)

Figure 2-7—Forwarder capable of transporting whole trees from stump to roadhead.

15 percent interest on entire capital cost, which roughly corresponds to a 15 percent profit on total investment in harvesting and support equipment. The $35 cost is derived from data in appendix II under the assumption that the smallest tree harvested will be 3 inches in d.b.h. with few over 8.9 inches in d.b.h., and that 44.7 percent of the trees will be in the 4-inch diameter class, 36.6 percent in the 6-inch class, and 18.7 percent in the 8-inch class (see the Lincoln County data in table 2-4).

In addition to the wood harvested and transported, as illustrated in figures 2-6, 2-7, and 2-8, from National Forest land, additional wood will be purchased from independent contractors operating on State and private land. The proportion of total cubic-foot volume of lodgepole pine growing stock on State and private lands is 34.4 percent in Flathead County, 15.7 percent in Lincoln County, and 14.3 percent in Sanders County (table 2-3). It is estimated that 80 percent of the total wood harvested will come from National Forests and 20 percent from State and private lands.

Transport costs, including profit on equipment investment, should be about $11 per ton of stemwood, ovendry basis. This estimate is based on a cost of $1.34 per round-trip mile over an average haul radius of 40 road miles, with a 26-ton load of green, whole trees containing $9^3/4$ tons of stemwood, ovendry basis.

Total cost, including profit on investment, for harvesting and hauling will therefore be about $46 per ton of ovendry stemwood (that is, $35 + $11). To this must be added about $1.25 per ton for administration of the procurement operation, yielding a total of $47.25 per ton of ovendry stemwood delivered to the plant. Under this costing system, bark and branchwood enter the plant at zero cost.

Organization of Wood Procurement Operation

The wood procurement operation will be set up as a corporation separate from the manufacturing corporation. The procurement corporation will do no harvesting with corporate crews, but will contract all harvesting operations. Most contractors will operate on a large scale, as described by figures 2-6 and 2-7. Others may use lighter and less expensive equipment, however.

In addition to the just-described contracted stand-replacement harvests from National Forests, it is anticipated that significant tonnages of woods-run, tree-length logs of mixed coniferous species will be purchased on the open market from independent loggers at a cost slightly lower than that computed for the stand replacement harvests. The cost of such purchased wood is estimated at

Figure 2-8—Whole pines with small crowns being grapple loaded on a truck for transport to mill.

$40 per ton of ovendry stemwood delivered to the plant, plus $1.25 per ton for administration of the wood procurement operation, for a total of $41.25 per ton.

2-6 SUMMARY

Data discussed in this chapter suggest that the optimum Montana location for the operations contemplated is in the Libby-Troy area (fig. 2-4) of Lincoln County, and that plant consumption of stemwood (ovendry weight basis) should probably not exceed 200,000 tons annually.

About 55 percent of this tonnage will be tree-length lodgepole pine stemwood not suitable for sawmills; the balance will be tree-length wood of mixed coniferous species (perhaps half lodgepole pine), some of which may be of sawlog size and quality.

The average cost of stemwood delivered to the plant should be about $47.25 per ton, ovendry-weight basis, for that harvested in stand-replacement operations. The purchased wood should cost about $41.25 per ton of stemwood, ovendry-weight basis. Overall average cost of wood should therefore be about $44.55 per ovendry ton, that is:

$$(110{,}000 \text{ tons} \times \$47.25 + 90{,}000 \text{ tons} \times \$41.25) \div 200{,}000 = \$44.55.$$

2-7 REFERENCES

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CHAPTER 3: PRODUCT MIX AND MATERIAL BALANCES

CONTENTS

3-1 WOOD CHARACTERISTICS

There are good reasons why lodgepole pine can be an important source of raw material for a broad range of products. First—as noted in chapters 1 and 2—substantial volumes of the timber are available now, and the resource is readily and economically renewable in pure stands over a broad range of sites. Second, the wood itself has an unusual combination of desirable properties, especially that grown in northwestern Montana.

The strength/weight ratio of lodgepole pine is outstanding, particularly in small-diameter, suppressed trees typical of those in most Montana stands—and these small-diameter trees do not have the large core of weak, short-fibered, distortion-prone juvenile wood so prevalent in many commercially important conifers of North America. When of sufficient size, lodgepole pine is a prime material for structural plywood and laminated-veneer lumber; trees of smaller diameter yield flakes admirably suited for structural flakeboards such as waferboard, oriented-strand panels, and oriented-strand lumber. Its light color and long fibers make it well suited for conversion to fiberboard products such as hardboard and medium-density fiberboard. For the same reasons, it is well adapted for pulping by both chemical and mechanical processes. Also, it is a premium species for the manufacture of 2 by 4 studs, and machine-stress-rated lumber for trusses. Further, the form of the trees favors their broad acceptance for rails, posts, small poles, and logs for cabins. The small branches and self-pruning attribute of the species facilitate manufacture of attractive, sound-knotted paneling and millwork; most consumers find esthetically pleasing the faint dimpled pattern visible on tangentially cut millwork surfaces of lodgepole pine. Among all North American species, lodgepole pine ranks near the top in compatibility with Portland cement, thus making it a favored candidate for wood-cement composite panels.

Small stem diameter is the principal factor limiting use of the species. Also, heartwood of lodgepole pine ranks among the least permeable of major commercial coniferous species in North America. Although knots in lodgepole pine are small and unobtrusive, they do tend to be dark—even black—in many stems. If red-knotted wood is required for a product, some visual grading of stem sections must precede manufacture. Also, spiral grain is occasionally severe in some stems; on kiln drying, such spirality may cause twist in both sawn and roundwood products.

3-2 POTENTIAL PRODUCTS

The need to clear-fell trees of all diameters and all species, and to utilize all those exceeding 3 inches in d.b.h. (see section 2-5) constrains product selection, as does the generally small diameter of even the largest stems. Because of the small average stem diameter, and the significant component of dead timber in the stands available, concentration on products utilizing rotary-cut veneer is deemed impractical—even if centerless lathes are employed.

Because of the magnitude of investment and resource required for pulp and paper production, and because of environmental considerations, manufacture of chemical pulp is perhaps not possible. Also for environmental reasons, wet-process fiberboard production is not considered a viable option. Favoring pulp or fiberboard production, however, is the availablity of low-cost pulp chips from sawmill residues in northwestern Montana.

After elimination of pulp and paper, wet-process fiberboard, and structural veneer products, there still remains a broad spectrum of potentially viable products. One way of screening these products is estimation of their plant-gate net sale price per ton, ovendry-weight basis (table 3-1). This information, along with estimation of product yield as a percentage of gross stemwood weight, evaluation of cost of the manufacturing operation, and value analysis of residues produced, provides some guidelines for rational selection of products.

Net sales realization per ton of stemwood input (ovendry basis) varies widely with product; also, labor input per product ton varies significantly. A summation of product net plant-gate prices (after deducting costs of resin and wax content) per ton of wood content, multiplied by the ratio of product output to stemwood input, less estimated labor cost per product ton (table 3-2), suggests the following order of manufacturing priority for profit potential (listed with greatest profit potential at top and least potential at bottom—without consideration of capital costs, energy costs, or other operating and administration costs):

Product	**Net sales revenue minus cost of resin and labor**
	Dollars per oven dry ton of stemwood input
2-inch tree props (doweled)	$158
$2^5/_8$-inch rails and tree props (doweled)	137
Edge-glued solid lumber panels	118
2 by 10 oriented-strand lumber	115
Fabricated pole joists	113
$^7/_{16}$-inch OSB sheathing	91
2 by 4 kiln-dried studs	49
8-foot 1 by 6 kiln-dry lumber	16
Pulp chips	15

Table 3-1—Product comparisons by volume, weight, net plant-gate sale price, and recovery ratio

Product	Volume	Sale price on a volume basis	Proposed product weight[1]	Net plant-gate sale price wood only[2]	Weight ratio of product output to stemwood input
	Ft³	*Dollars*	*Pounds ovendry*	*Dollars per ton*	*Percent yield*
Pulp chips	96	22	2,400	18	95
	- - - - - - - - - - - - - per unit - - - - - - - - - - - - - -				
7/16-inch flakeboard	36.5	130	1,422	156	80
	- - - - - - - - - - - per thousand ft² - - - - - - - - -				
2 by 10 structural lumber	59.4	240	2,234	189	79
	- - - per M bd ft - - - -		- - - - - - - - - - oriented-strand lumber - - - - - - - - - -		
2 5/8-inch doweled tree props and rails	37.6	150	1,009	297	60
	- - - - - - - per thousand lineal feet - - - - - - - -				
8-ft 1 by 6 boards	57.3	150	1,433	209	33
	- - - - - - - per M bd ft, solid-sawn - - - - - - - - -				
2 by 4 studs	54.7	180	1,368	263	33
	- - - - - - - per M bd ft, solid-sawn - - - - - - - - -				
2-inch tree props	21.8	95	572	332	60
	- - - - - - - per thousand lineal feet - - - - - - - -				
Fabricated pole joists	85.2	700	2,575	500	45
	- - - - - - - per thousand lineal feet[3] - - - - - - - -				
Edge-glued solid lumber panels	125.0	750	3,588	401	50 (after shaping-lathe round-up)
	- - - - - - - per thousand ft² 1.5 inches thick - - - - - - - -				

[1]Wood only, exclusive of resin and wax.
[2]After deducting cost of resin and wax.
[3]Assumes two lineal feet of 12-inch-deep joist produced for each foot of 10-inch-deep joist.

Table 3-2—Estimation of net sales realization, by product, per ton of stemwood input (ovendry weight basis) after deducting costs of resin, wax, and labor (including common services and management)

Product	Percent yield multiplied by product sale price per ton (from table 3-1)	Estimated labor input per ton of product	Percent yield multiplied by (sale price less labor cost at $12.50 per hour)
	Dollars per ton, ovendry	*Worker-hours*	*Dollars per ton of stemwood input, ovendry*
2-inch tree props	$199	3.3	158
2 5/8-inch rails and tree props	178	3.3	137
Edge-glued solid lumber panels	200	6.6	118
2 by 10 oriented-strand lumber	149	2.7	115
Fabricated pole joists	225	9.0	113
7/16-inch OSB sheathing	125	2.7	91
2 by 4 kiln-dried studs	87	3.0	49
8-foot 1 by 6 kiln-dried lumber	69	4.2	16
Pulp chips	17	.2	15

These data, and knowledge that most stem sections are of sub-sawlog size, suggest that this analysis should concentrate on structural flakeboard (for market, probably oriented-strand board because orientation of face and core layers is the most economical way of obtaining needed mechanical properties), possibly oriented-strand lumber, tree props (rails and posts, while not unattractive in price are sold mostly in local markets), fabricated joists, and edge-glued lumber millwork panels (figs. 3-1 through 3-7).

The remainder of this chapter discusses these potential products and estimates material balances resulting from their manufacture.

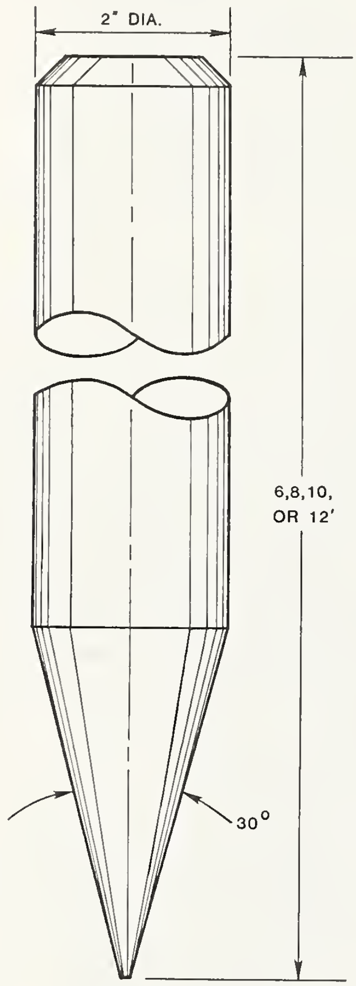

Figure 3-1—Dimensions of 2-inch tree prop.

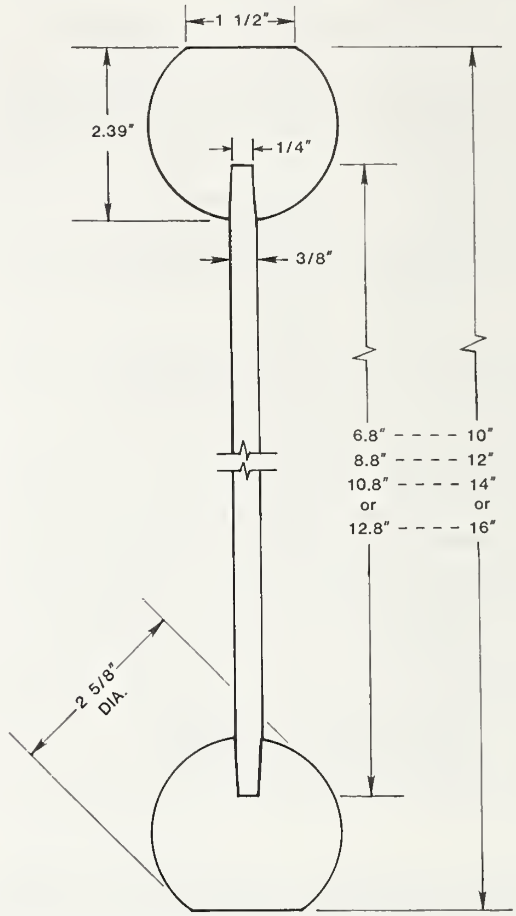

Figure 3-2—Proposed commercial designs of pole joists 10, 12, 14, and 16 inches in depth. Flanges are pith-centered lodgepole pine dowels; webs are 3/8-inch-thick structural flakeboard.

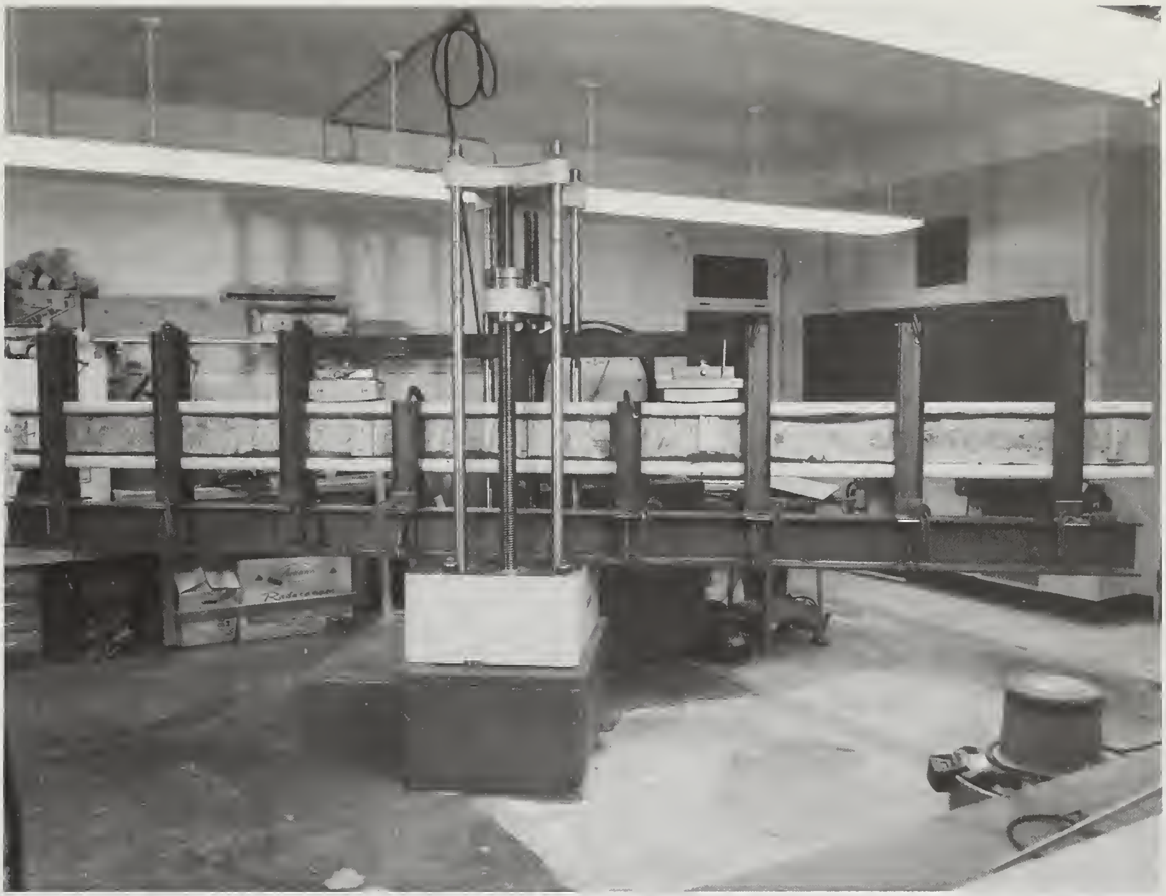

Figure 3-3—Fabricated pole joist 16 feet long undergoing a destructive bending test with third-point loading over a 15-foot span.

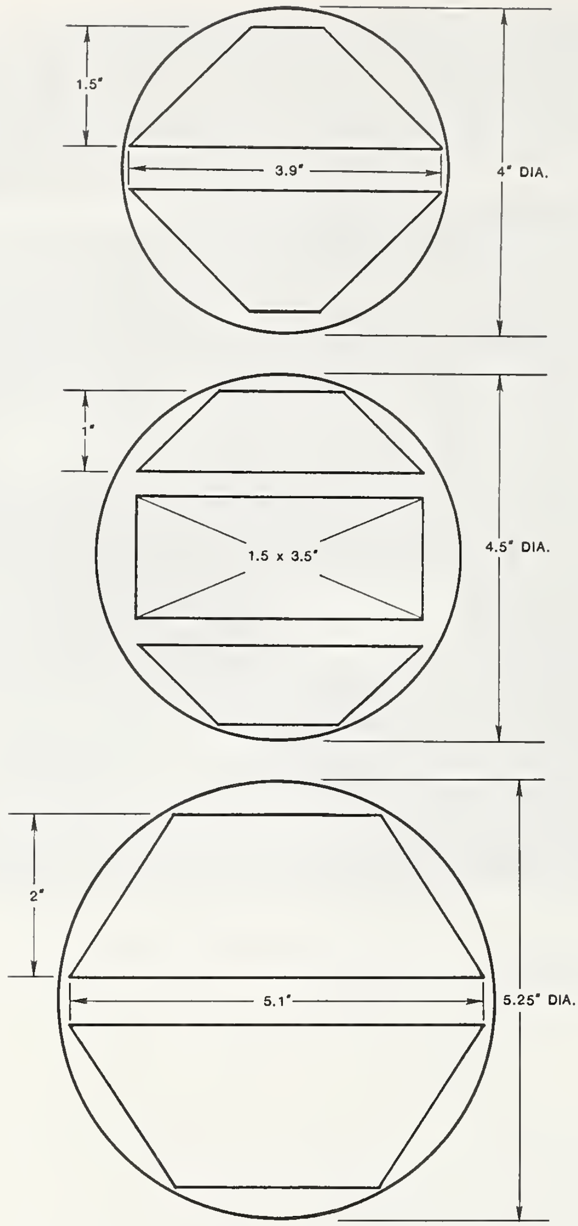

Figure 3-4—Typical small-log cutting patterns designed to yield kiln-dried, fully machined trapezoidal shapes for utilization in edge-glued panels; to simplify the drawings, toothing on the beveled edges is not shown. Diameters indicated are for kiln-dry half-cylinders; green dowels, before resawing, would be about 0.2 inch larger in diameter.

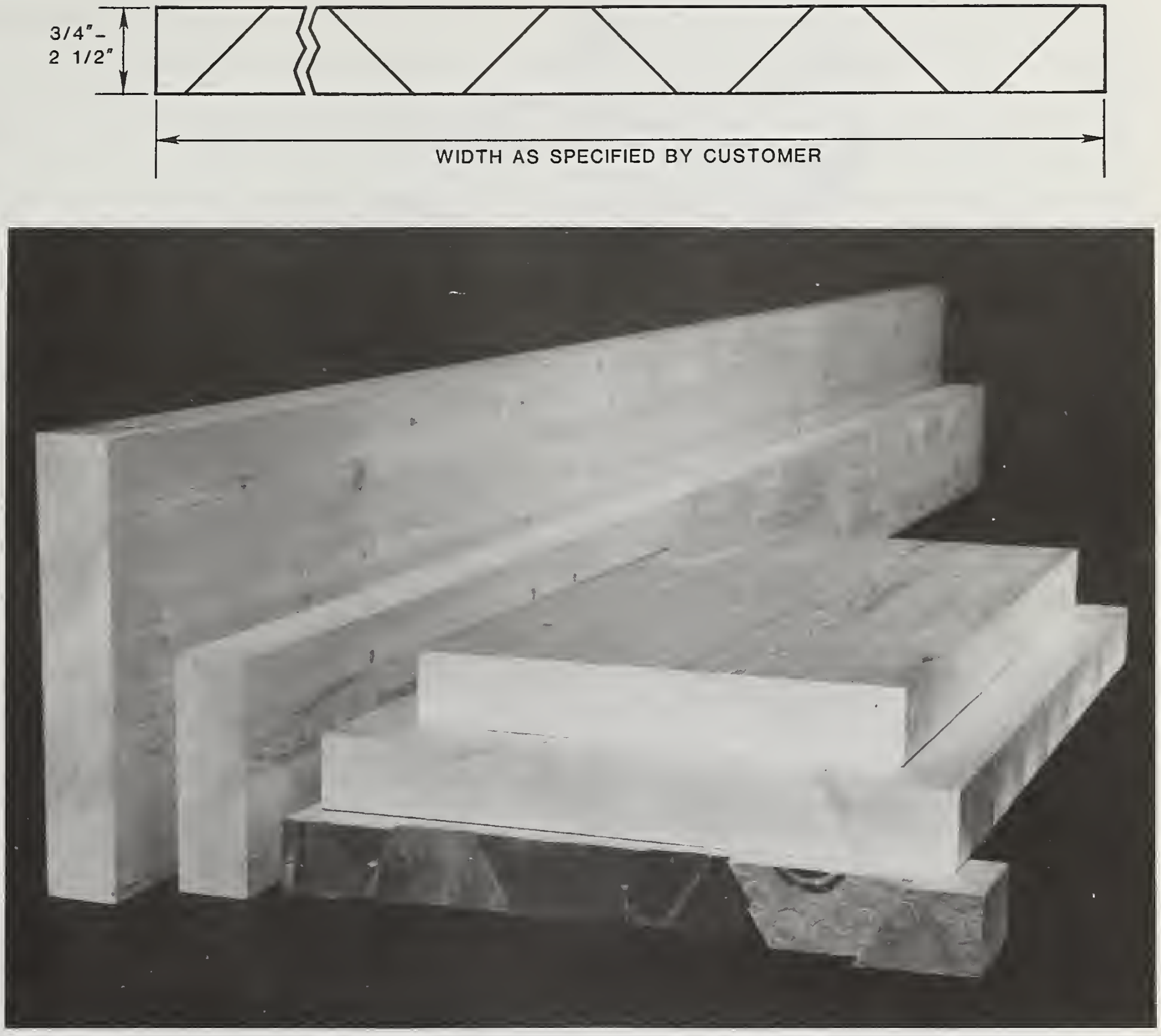

Figure 3-5—(Top) Panel cross section showing geometry of assembly. (Bottom) Glue lines in the completed panels are nearly invisible; knots are typically small, sound, and distributed over both surfaces.

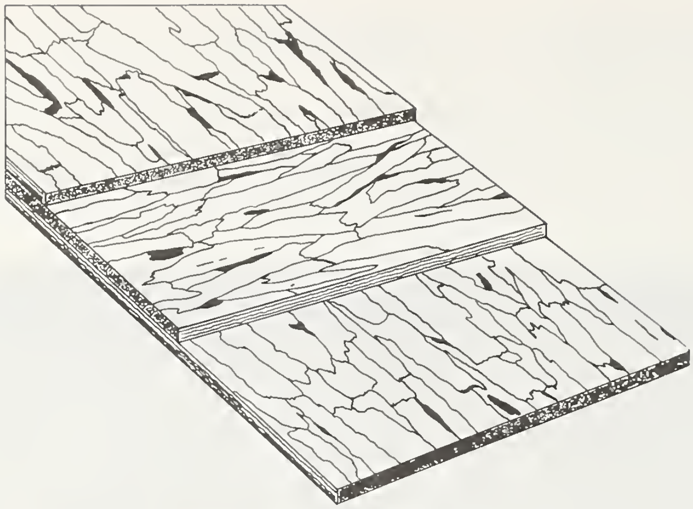

Figure 3-6—Structural three-layer oriented-strand board; flakes in the two face layers are aligned with grain parallel to the long edge of panels as they are pressed—for example, in 8-foot-wide by 32-foot-long size; those in the core are at right angles to this.

Figure 3-7—Oriented-strand board installed as floor decking (foreground) and wall and roof sheathing (typically $^{7}/_{16}$ inch thick) on a residence; shingles will be installed over the roof sheathing.

Composite Panels

Structural flakeboard products such as waferboard, oriented-strand board (figs. 3-6 and 3-7), and oriented-strand lumber can be advantageously manufactured from the available resource. Manufacture of such products, while capital-intensive, requires relatively low labor and power input; moreover, a high proportion (about 80 percent) of the weight of stemwood sections admitted to the process can be converted into products with a net plant-gate sale value of perhaps $175 per ton, ovendry. The sale value of $175 per ton includes about $19 of wax and phenol-formaldehyde (P/F) resin, leaving a net of about $156 per ton of ovendry wood in the product. The process requires raw material in roundwood form—as opposed to wood in pulp-chip or other particulate form—and it is therefore not suited for utilization of residues from other manufacturing operations. It is also recognized that fixed-disk flakers should be fed bolts larger than 4½ or 5 inches in diameter if standard productivity is to be maintained. Moving-head flakers (disk or drum) capable of flaking bundles of random-length logs can accommodate stems of smaller diameter, but the quality of flakes cut from very small stems will likely be lower than the quality of those cut from larger wood.

Dry-process medium-density fiberboard (MDF) does not require roundwood furnish; while basically manufactured from pulp chips, its furnish can accommodate significant quantities of coarsely hogged wood (even including some bark), shavings, and coarse sawdust. Thus, in a multiproduct manufacturing operation, the residues from other products can be incorporated in MDF to boost overall product yield—a significant advantage. MDF has a net plant-gate sale value of about $189 per ton of ovendry board; while this value appears high in relation to structural flakeboard, it contains a large increment of power cost—perhaps $27 per ton—as well as significant resin cost. As a result, the net per ton of ovendry wood in the product is not greatly different from that for flakeboard. Moreover, the very large energy demand of the required defibrators (perhaps 3.5 megawatts for a plant of viable size), suggests that any such plant generate its own power from wood residues—thus adding to the complexity of the plant and significantly increasing capital costs.

The markets for both MDF and structural flakeboard are expected to grow significantly in the next few decades (chapter 9); however, the market for MDF is primarily tied to the furniture industry—mostly located far distant from Montana in the Southeast, the Northeast, and southern California. The market for structural flakeboard, in contrast, is primarily tied to the residential housing market throughout the United States, and Western States are expected to show more than average growth in housing starts. Moreover, the market for structural flakeboard (tons sold) is several times larger than that for MDF. Currently there is one plant manufacturing MDF in Columbia Falls, MT; there are no manufacturers of structural flakeboard in the State. In spite of the significant advantage of the MDF process in absorbing other manufacturing residues, structural flakeboard—particularly oriented-strand board (fig. 3-6)—appears to be the better choice.

An entrepreneur with markets for MDF, however, might more closely study the tradeoffs between the manufacture of MDF and structural flakeboard. For a multiproduct plant with a total intake of 200,000 tons, ovendry, of stemwood (fig. 3-8), selection of MDF rather than flakeboard could boost composite panel production—through incorporation of residues from other plant manufacturing operations—by about 35,000 tons annually, and would add perhaps $5 million to annual sales. With an inhouse generating facility, power purchases would be diminished by about $1 million (from those incurred manufacturing flakeboard and the product mix shown in figure 3-8). Offsetting these gains are the capital costs and operating costs of a 7- or 8-megawatt generating facility.

Another possibility is manufacture of wood-cement composite panels (there is a cement plant in Metaline Falls, WA, with convenient truck and rail access to the Libby-Troy area). Lodgepole pine ranks near the top among North American species in compatibility with Portland cement (Moslemi and Pfister 1987). Although wood-cement composite panels are widely used in Europe, Mexico, and other regions where high material resistance to fire, insects, and decay is required, there are no manufacturing facilities in the United States.

Typically wood/cement ratios are about 1:3 on an ovendry-weight basis. Green wood residues (such as those from doweling machines) can be utilized without drying, as the process needs water for hydration of the cement binder. Panels are typically cold pressed and air cured in ½-inch thickness to a density of about 80 lb/ft^3. Panel modulus of elasticity is typically in the range from 650,000 to 850,000 lb/in^2, and modulus of rupture in the range from 2,000 to 2,400 lb/in^2.

The high density of wood-cement composite panels would probably limit market radius to the Missoula-Coeur d'Alene-Spokane-Sandpoint area. At a plant-gate net sale price of $120 per ton of ½-inch panel ($200 per M ft^2), the margin remaining for the wood component and all manufacturing costs and profit would be about as follows:

Wood-cement composite panel price per ton	$120
Cost of cement (1,500 pounds) in a ton of panel	56 (at $75/ton)
Margin for wood (500 pounds) and manufacturing cost	64 ($256/ton of wood)

To manufacture such panels, bark-free, green, wood residues (coarse particles from dowel machines, for instance) are ring-flaked and blended with water, cement, and other chemicals in a horizontal drum with agitators. Air classifying heads form a graduated mat with a superfine surface. Mats (about 4 by 8 feet in size) are placed on steel cauls and stacked in a clamp-cradle closed under pressure. The clamp-cradle is then removed from the cold press and transported to a slightly heated curing chamber where it remains for 10 hours. The press is then employed a second time to permit removal of locking pins from the clamp-cradle. The partially cured panels are removed, trimmed to size, and further cured for 14 days at ambient temperature. Finally they are conditioned to 12 percent moisture content.

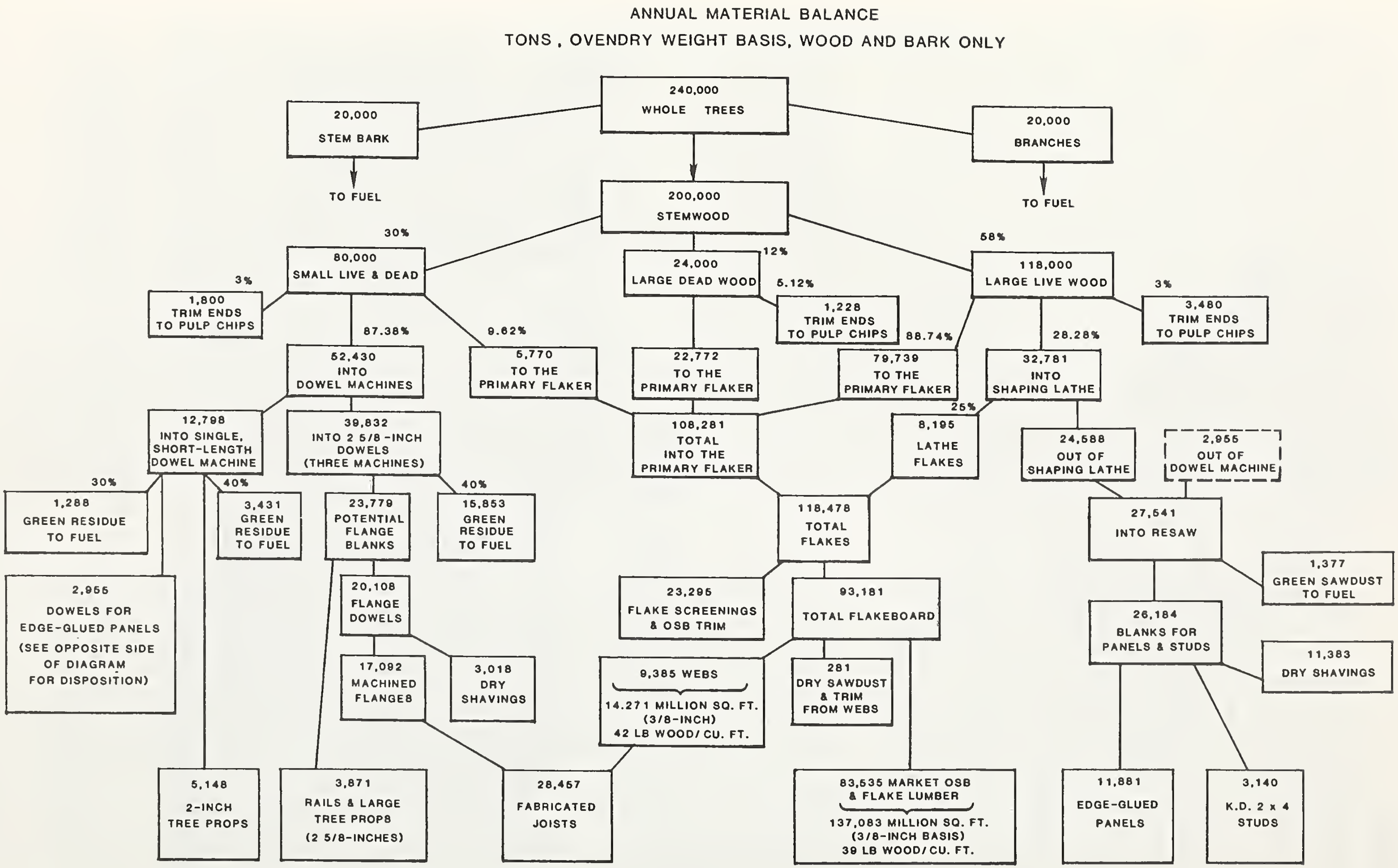

Figure 3-8—Wood and bark material balance based on annual tonnage (ovendry weight basis). Weights of resins and wax incorporated in the products are not included.

There is no established market in the Intermountain region for this type of panel, but an entrepreneur willing to establish a market might find that wood-cement composites are a potential end use for excess residues not salable as pulp chips or needed for fuel. If 25 million ft^2 of $^1/_2$-inch composite panel (41,668 tons, grossing $5 million) could be sold annually in the region, the wood component would total about 10,417 tons (ovendry) annually.

The product is not considered further here, but it appears to have some possibilities as a means to market excess green residues.

Oriented-Strand Board—Structural flakeboard plants in North America are increasingly manufacturing oriented-strand board (OSB) rather than waferboard with randomly oriented flakes. The major product manufactured is $^7/_{16}$-inch-thick sheathing for use under shingles or siding in residential construction (see chapter 9). Other OSB products include thicker panels for decking, and thinner decorative panels. Depending on the density of the parent wood, density of the panels is generally in the range from 37 to 45 lb/ft^3, ovendry weight basis; of this weight 3 to 4 percent is P/F resin and about 1 percent wax. For lodgepole pine OSB, an ovendry panel density of 41 lb/ft^3 should yield acceptable panel properties.

As noted later, a significant proportion (about 10 percent) of the output of the proposed flakeboard plant will be manufactured as webs for fabricated pole joists. These webs—to enhance inplane shear strength—will have random flake orientation and higher density than the market OSB.

In North America, plants manufacturing OSB typically range in size from 100 million to 300 million ft^2 annually ($^3/_8$-inch basis). Manufacturing economies of scale are significant. Midsize plants (150 to 160 million ft^2 annually) have perhaps $10 per thousand ft^2 lower costs than the smallest plants; the largest plants enjoy a similar cost advantage over the midsize plants. Wood supply in the Libby-Troy area probably limits panel production—when meshed with a multiproduct operation (fig. 3-8)—to about 150 million ft^2 annually, $^3/_8$-inch basis.

Oriented-Strand Lumber—Gradual liquidation of old-growth timber in North America, followed by replacement with smaller diameter trees, has resulted in scarcity of wide, long, high-quality structural lumber of uniform strength. Because of this scarcity it is probable that, within a decade or two, oriented-strand structural lumber will be a significant factor in the lumber market.

Already minor factors in the structural lumber market, parallel-laminated-veneer lumber and lumber laminated from long (>6 inches) veneer strands show promise of increasing market penetration. These high-performance products have modulus of elasticity (MOE) values near 2 million lb/in^2, and command prices near $1,000 per M bd ft.

It seems likely that oriented-strand lumber with somewhat lower MOE—perhaps 1.4 million lb/in^2—selling at a price competetive with upper structural grades of solid-sawn lumber (such as $240 per M bd ft), will emerge as a strong competitor in the market. Such lumber would be comprised of flakes only about 3 inches long (the same as for OSB) and could be made in the same presses as OSB—but with double or triple usual OSB resin content.

The usual OSB presses for a plant of the size contemplated have perhaps 16 openings with platens 8 feet wide, and 16 feet long. By equipping the proposed plant with an 8-opening press having 8-foot-wide platens 32 feet long (instead of 16 feet), and sufficient space between platens (daylight) to accommodate mats thick enough for $1^1/_2$-inch-thick panel products, the plant would be in a position to make fully oriented-strand lumber in lengths to 32 feet and widths specified by the customer.

Tree Props

Structural flakeboard can be made from most species of wood in North America, and lodgepole pine has no particular advantage over other low-density woods available. For a few specialized products, however, lodgepole pine has a significant advantage over other species. Because of its small diameter, superior stem form (little stem taper), high strength/weight ratio, small branch diameter, and lack of a weakening juvenile-wood core, lodgepole pine is unique in North America as a species adapted for manufacture of pith-centered structural dowels and small-diameter roundwood products.

During the last decade a significant market has been developed in the Southwest—particularly in California—for 6- to 12-foot-long pith-centered lodgepole pine dowels for use as tree props (fig. 3-1). The major demand is for props 2 inches in diameter and 8 or 10 feet long, although $1^1/_2$-inch props are also in demand. In addition to tree props sold to orchardists and landscapers, the agricultural industry consumes large numbers of doweled products such as stakes, posts, and rails of various dimensions in vineyards, hop fields, berry farms, and pastures. Idaho and Montana producers of these products have done an outstanding job of developing and expanding markets for these products in the Southwest, but none have made significant efforts to develop Midwest markets.

Stem sections suitable for 2-inch tree props measure about $2^1/_8$ to $2^1/_4$ inches in diameter inside bark at the small end, and about $2^3/_4$ inches at the large end; stem section lengths for this purpose are predominantly 96 or 120 inches long but may be as short as 72 inches and as long as 144 inches.

Doweling machines used in the industry can produce, under good conditions, about 2,200 tree props per 8-hour shift. If run three shifts, 350 days a year, a single machine should annually produce about 5,146 tons of 2-inch tree props (about 2 million pieces averaging 9 feet long) plus perhaps 2,955 tons (ovendry basis) of larger dowels. Residue from the dowel machine should total about 4,697 tons—in a form not suitable for sale as pulp chips, but usable in boilers capable of burning green fuel.

Fabricated Joists

There are many designs of joists available in the U.S. market. The dominant Northwest products in the wood-joist market, however, are probably machine-stress-rated

(MSR) kiln-dried 2 by 10's and 2 by 12's, and the $9^{1}/_{2}$-inch-deep and $11^{7}/_{8}$-inch-deep joists fabricated in Idaho and Oregon with laminated-veneer flanges and plywood webs. The solid lumber product is generally available in random lengths from 10 to 20 feet, while the fabricated joists are rail-shipped in 64-foot (or even 80-foot) lengths to distribution yards where they are cut to exact lengths according to each builder's needs; short lengths are cut into blocking needed to laterally stabilize the joists. Where uniformity of stiffness and strength are not critical, much kiln-dried 8/4 #2 fir and larch in 10- and 12-inch widths is also sold for joists.

Starting from the well-accepted premises that minimally machined cylindrical stemwood is significantly stronger and has higher MOE than sawn lumber of the same cross section (Doyle and Wilkinson 1969), and that structural flakeboard has high inplane shear strength (Chen and others 1989), a series of experiments were executed to develop fabricated joists utilizing minimally machined lodgepole pine stems as flanges and structural flakeboard as webs (Burke and Koch 1986; Burke and Koch 1987; Koch and Burke 1985; see also appendix III).

As originally conceived, two designs were described (Koch and Burke 1985). The first of these designs employed flanges made of dowels (more or less pith-centered) machined from whole stems. The second employed somewhat larger dowels center-split to yield a pair of flanges from a single stem; in cross section these joists have somewhat the shape of a stemmed wine glass. For a variety of reasons explained in Burke and Koch (1987), the second design was dropped in favor of the first (fig. 3-2).

The research program cited yielded products competitive to solid-sawn 2 by 10's and 2 by 12's. These fabricated pole joists (figs. 3-2 and 3-3) are lighter than most fir and larch lumber joists but heavier than the competitive fabricated joists with laminated-veneer flanges. They are, however, significantly stiffer (have greater EI) than these competitive products and have significantly higher maximum resistive moment (load carrying capacity in edgewise bending) at 100 percent of design load (table 3-3 and appendix III).

Because, in the United States, the specific gravity of lodgepole pine stemwood is positively correlated with latitude (Koch 1987, fig. 4-44), trees grown in northern Montana should have significantly higher mechanical properties than those grown farther south. This supposition was confirmed by tests of lodgepole pine stemwood sections in compression parallel to the grain; the tests showed that stemwood from small trees sampled in Montana had significantly higher MOE and ultimate

Table 3-3—Comparison of depth, weight, stiffness (EI), bending strength (design resistive moment), and maximum vertical shear (100 percent of design load) of proposed fabricated lodgepole pine pole joists with machine-stress-rated Douglas-fir and larch kiln-dried lumber, and with competitive Douglas-fir fabricated joists having laminated-veneer flanges and plywood webs

Property	MSR lumber 1.5E - 1650f	Competitive fabricated joists	Proposed fabricated joists (fig. 3-2)
2 by 10's			
Depth, inches	$9^{1}/_{4}$	$9^{1}/_{2}$	10
Weight/lineal foot at 10-percent moisture content, pounds	2.7	1.9	2.9
EI, million inch² pounds	148	[1]170	253
Maximum resistive moment at 100 percent of design load, foot pounds	2,938	[1]2,940	7,096
Maximum vertical shear at 100 percent of design load, pounds	902	805	946
2 by 12's			
Depth, inches	$11^{1}/_{4}$	$11^{7}/_{8}$	12
Weight per lineal foot at 10-percent moisture content, pounds	3.8	2.0	3.1
EI, million inch² pounds	267	285	387
Maximum resistive moment at 100 percent of design load, foot pounds	4,346	3,935	9,333
Maximum vertical shear at 100 percent of design load, pounds	1,068	990	1,000
2 by 14's			
Depth, inches	—	14	14
Weight per lineal foot at 10-percent moisture content, pounds	—	2.82	3.3
EI, million inch² pounds	—	550	516
Maximum resistive moment at 100 percent of design load, foot pounds	—	6,450	11,595
Maximum vertical shear at 100 percent of design load, pounds	—	1,160	1,000
2 by 16's			
Depth, inches	—	16	16
Weight per lineal foot at 10-percent moisture content, pounds	—	2.98	3.5
EI, million inch² pounds	—	745	636
Maximum resistive moment at 100 percent of design load, foot pounds	—	7,570	13,871
Maximum vertical shear at 100 percent of design load, pounds	—	1,315	1,000

[1]These are sales-bulletin values. Our destructive tests of five of these Douglas-fir joists indicated an EI of 127 million inch² pounds, and a value of 1,725 foot pounds for maximum resistive moment at 100 percent of design load in bending.

compressive strength than stemwood sampled from other States in the lodgepole pine range (Koch and Barger 1988). This phenomenon appears to give Montana operators an advantage over potential joist manufacturers in other States within the lodgepole pine range.

Doweling tests by Burke and Koch (1987) indicate that stem sections selected to be doweled for flanges should be 16 feet long, free of large bark inclusions and large knots, with sweep less than 1¼ inches, and with spiral grain of less than 5 degrees. For dowels turned green to a diameter of 2⅝ inches for use as flanges, stem-section top diameter inside bark should be about 2.8 inches, with butt diameter averaging about 4.0 inches. These proportions will yield about 40 percent residues. In general, stem sections appropriate for flange dowels are found in whole stems just below the portions suitable for manufacture into tree props.

After kiln drying, flange dowels will be nondestructively tested for MOE, and those below the acceptable threshold (perhaps 15 percent if the lower threshold MOE for flanges at 10-percent moisture content is 1.5 million lb/in^2) will be marketed as rails or remanufactured into tree props.

Plant observations indicate that a single dowel machine can routinely produce about a thousand 16-foot-long dowels per 8-hour shift, that is, 16,000 lineal feet. If operated three shifts for 350 days per year (1,050 shifts - 50 maintenance shifts), a single dowel machine should produce about 16 million lineal feet per year.

Because 1 lineal foot of such a dowel 2⅝ inches in diameter has an ovendry weight of about one pound, annual output per machine should be about 16 million pounds or 8,000 tons of dowels.

Because production plans (fig. 3-8) call for 23,779 tons of flange dowels annually (ovendry-weight basis), three fully operational machines will be required. To obtain this tonnage of dowels, about 39,632 tons of stemwood will be admitted to the machines annually (fig. 3-8).

Of the 23,779 tons of candidate flange dowels, about 15 percent (3,671 tons annually) will be culled for rails and tree props as noted previously. From the acceptable kiln-dried dowels, about 15 percent of the weight will be removed in the form of shavings produced during finger-jointing and assembly to 64-foot lengths, dadoing a groove to receive the web, and machining the finished joist to prescribed dimensions (fig. 3-2). Thus about 17,092 tons (41.100 million lineal feet, sufficient for 20.550 million lineal feet of joists) will end as machined flanges. Also produced will be about 3,016 tons of dry shavings usable for fuel or salable as particleboard furnish.

About 9,365 tons (ovendry) of ⅜-inch flakeboard will be needed annually to assemble with the 17,092 tons of flanges. These computations are based on the assumption that sales of 2 by 12 fabricated joists will be double the lineal footage of 2 by 10 joists.

Edge-Glued Lumber Panels

The transition from large timber to smaller trees grown on short rotations has affected not only structural lumber markets, but also markets for millwork grades of lumber. With the passing of readily available old-growth, large-diameter ponderosa, eastern white, Idaho white, and sugar pines, the price of wide 5/4 through 10/4 millwork-grade pine lumber with small sound knots has risen significantly. In 1987, edge-glued panels of such wood were offered only at prices near $1,000 per M bd ft—and most market experts forecast increasing prices.

This shortage of millwork-grade wood of traditional species offers an opportunity to capitalize on the light color, soft texture, straight grain, lack of a large core of inferior juvenile wood, and attractive knot pattern of lodgepole pine. While edge-glued panels are commonly assembled from components rectangular in cross section, there is no technical reason why they cannot be assembled from boards trapezoidal in cross section (figs. 3-4 and 3-5) if board edges are suitably toothed to prevent slippage under edge pressure during glue assembly. Conversion of small-diameter logs into boards trapezoidal in cross section can be both rapid and efficient, with product yields as good or better than recoveries of square-edged boards from larger logs (fig. 3-4).

A log merchandising deck of the kind envisioned for the manufacturing operation under analysis permits selection of stem sections with desired knot structure before they are cut to prescribed length, and sorted into narrow diameter classes to maximize lumber yield. Typically, stem sections 100 inches long would be turned to cylindrical form on a shaping lathe (fig. 3-9) to yield flakes for OSB as a residue. The cylinders would then be center-ripped, with or without recovery of a pith-centered board, kiln-dried, face-jointed on the sawn surface, and moulded to trapezoidal shape (fig. 3-4) prior to assembly into panels (fig. 3-5).

Machine observations indicate that a single 100-inch shaping lathe can turn about 1,680 100-inch-long stem sections into cylinders per 8-hour shift. If the bark-free stem sections have average small-end diameter of 5 inches, and large-end diameter of 5¾ inches, and the lathe operates three shifts per day for 350 days per year less 50 maintenance shifts annually (to match operating days of the OSB plant), annual input to the shaping lathe should be about 32,781 tons of stemwood (ovendry-weight basis), and output of cylinders will be about 75 percent of this tonnage, or 24,586 tons—assuming bolts are selected for roundness and straightness. Flake output from the lathe should therefore be about 8,195 tons.

Because small-diameter bolts are better suited to a doweling machine, about 2,955 tons (ovendry basis) of such smaller dowels will supplement those from the shaping lathe to yield a total of 27,541 tons admitted to the resaw at the beginning of the process to manufacture edge-glued panels (fig. 3-8).

Yield of edge-glued panels (11,661 tons) and studs (3,140 tons) should comprise about 54 percent of the weight of the cylinders and dowels admitted to the resaw (ovendry-weight basis). The ovendry-weight yield of edge-glued panels and studs from the bark-free bolts entering the process (selected for diameter, knot structure, straightness, and roundness) should be about 40 percent.

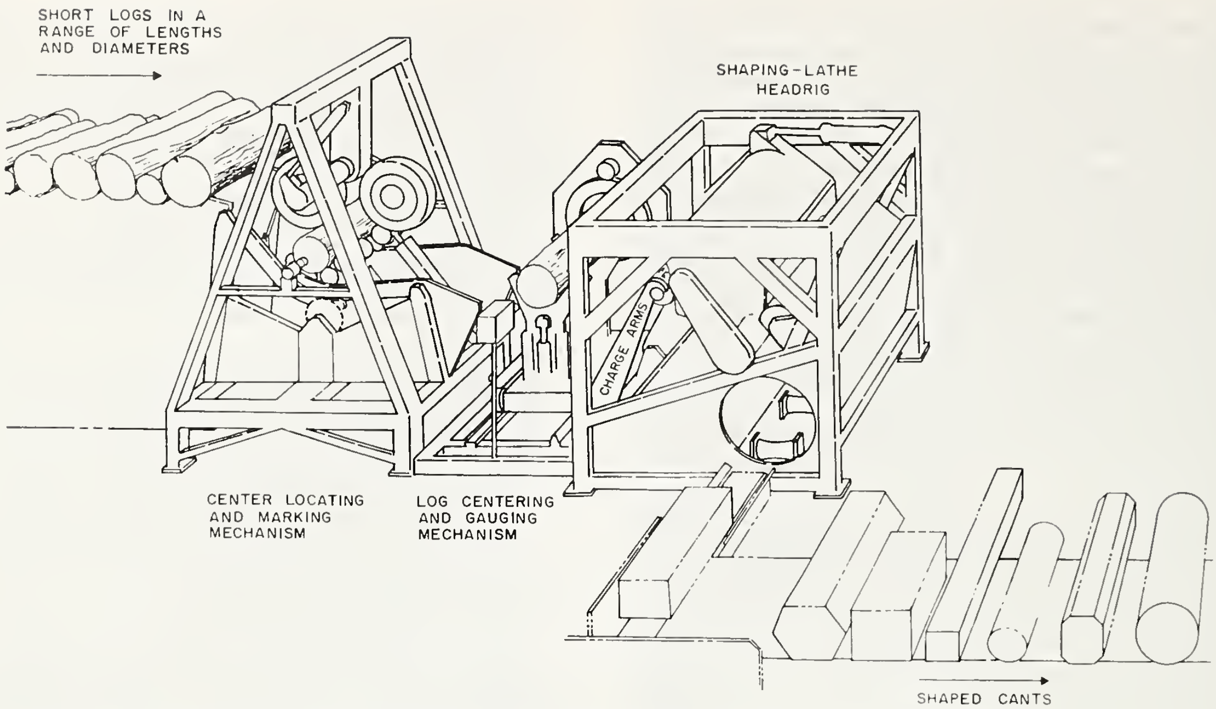

Figure 3-9—Shaping lathe headrig designed to produce cylinders or polygons of various dimensions. For the application described in the text, all logs would measure 100 inches long and would be machined into cylinders. Machine residue is in the form of flakes suitable for OSB. (Drawing after Koch 1985, p. 1921.)

3-3 MATERIAL BALANCES

With annual plant input of 200,000 tons of stemwood (ovendry-weight basis), and tree props, rails, fabricated pole joists, edge-glued lumber panels, and studs produced in the tonnages described in the foregoing paragraphs (fig. 3-8), output of structural flakeboard should be about 93,181 tons—9,646 tons used annually for webs in fabricated joists, (including dry sawdust and trim from webs), and the balance (83,535 tons) sold as market OSB. As noted earlier, the web material will have random flake orientation and be denser than the market OSB. On a 3/8-inch-thickness basis, total annual flakeboard output will be about 151 million ft^2 (fig. 3-8).

Residues from plant operations should be about as follows (fig. 3-8):

Residue description	Annual production	
	Tons, ovendry basis	
Salable		
Pulp chips	6,508	
Dry shavings	14,379	
		20,887
Fuel for plant consumption		
Dry flake screenings and trim	23,576	
Bark	20,000	
Green hog fuel	41,927	
		85,503
Total residues		106,390

Annual output (wood-content weight, and other measures) of salable products—excluding pulp chips and other residues—should be about as follows (fig. 3-8):

Product	Wood content, ovendry	Market measure
	Tons	
2-inch tree props	5,146	2 million pieces averaging 9 feet in length
2 5/8-inch tree props and rails	3,671	520,000 pieces averaging 14 feet long
Fabricated joists	26,457	6,850,000 lineal feet of 10-inch joists and 13,700,000 lineal feet of 12-inch joists
Edge-glued panels	11,661	6,500,000 ft^2 averaging 1 1/2 inches in thickness
2 by 4 studs	3,140	4 million bd ft
Market OSB	83,535	117,500,000 ft^2 of 7/16-inch sheathing
Total	133,610	

3-4 SUMMARY

Based on an annual input of 200,000 tons of stemwood and 40,000 tons of stembark and branches (ovendry-weight basis), high-value products totaling 133,610 tons (67 percent of stemwood weight) should be produced. Of

the residual 106,390 tons of stemwood, bark, and branches, about 20,887 tons will be sold as pulp chips or particleboard furnish; the remainder will be burned as fuel to produce process heat for the plant.

Net plant-gate sales values represented by these tonnages total $38,194,000 (table 9-1).

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CHAPTER 4: PRODUCT PROPERTIES

CONTENTS

4-1 TREE PROPS

As noted in section 3-2, tree props (fig. 3-1) are generally sold in lengths of 6, 8, 10, or 12 feet; the principal market is for 8 and 10 footers. Two-inch-diameter props are predominant, but diameters may be as small as 1½ inches and as large as 3 inches. The props are machined to uniform diameter from small stems so that stem piths are more or less centered in cross section.

Of importance to users of tree props are the mechanical properties of modulus of elasticity (MOE), which is a determinant of stiffness of the prop, and strength in tension and compression, which are determinants of strength in bending. Also, the dry weight of the props (a function of the wood specific gravity) is of interest because light weight lowers freight cost and eases handling. Additionally, permeability is of interest because most tree props must be pressure treated with preservatives—usually CCA (chromated copper arsenate). Not least in importance is straightness when shipped, installed, and in service.

As reported by Koch (1987), lodgepole pine stemwood from trees of small diameter has significantly higher specific gravity and mechanical strength than stemwood of the larger trees on which "Wood Handbook" (USDA FS 1974) data were based (figs. 4-1 through 4-7).

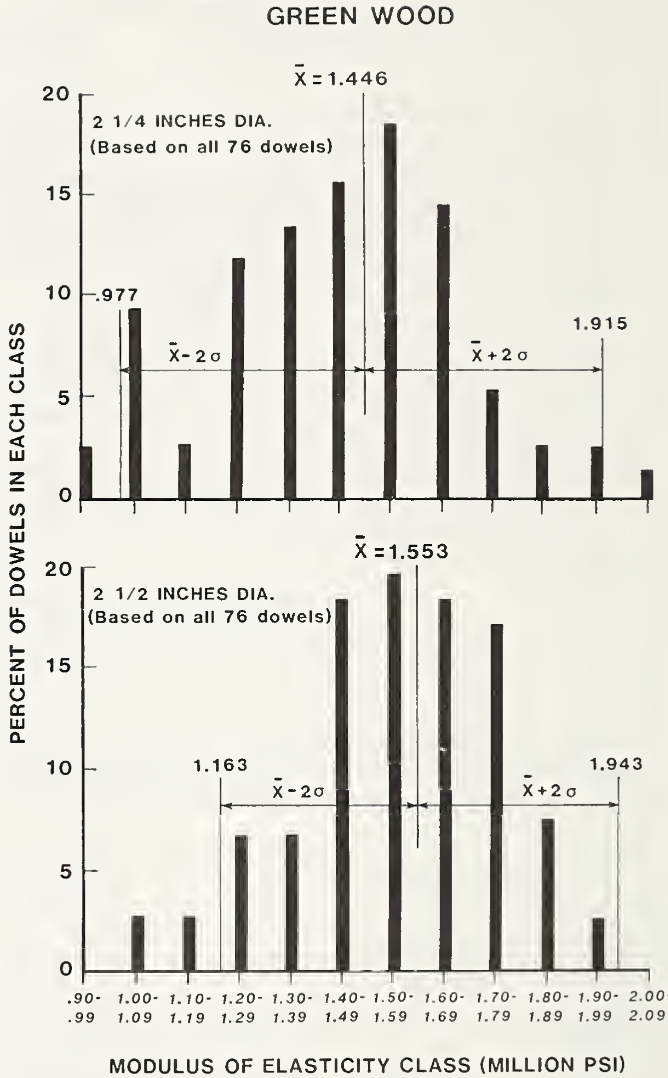

Figure 4-1—Distribution of values of modulus of elasticity at green moisture content for 2.25-inch- and 2.50-inch-diameter dowels machined from lodgepole pines sampled in the area from Libby to West Glacier in Montana.

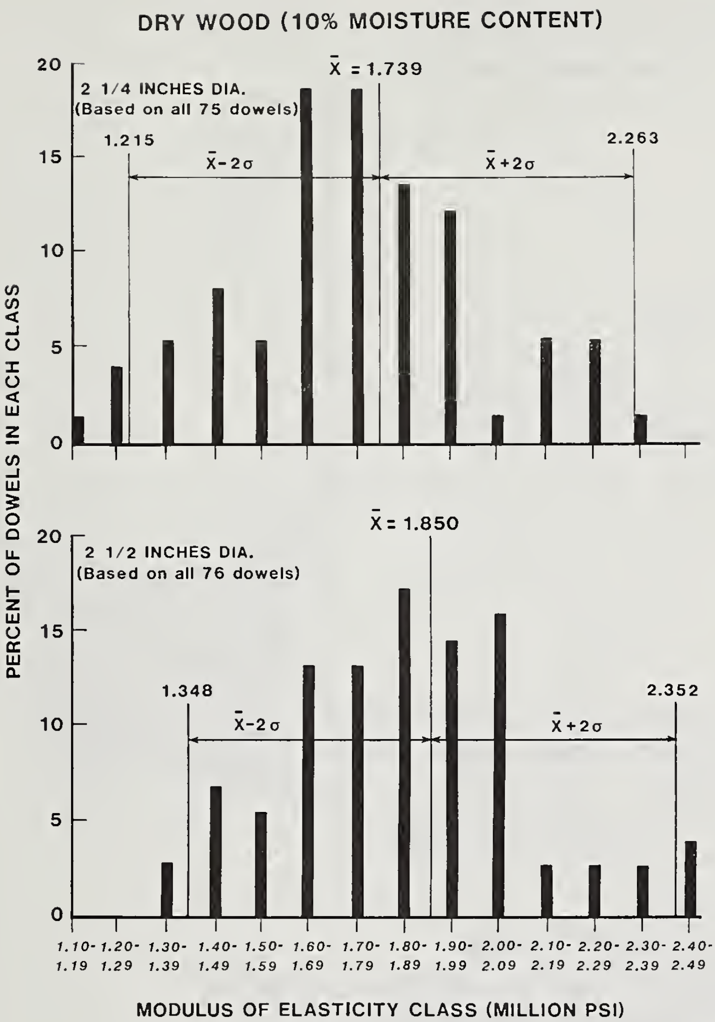

Figure 4-2—Distribution of values of modulus of elasticity at 10 percent moisture content for 2.25-inch- and 2.50-inch-diameter dowels machined from lodgepole pines sampled in the area from Libby to West Glacier, MT.

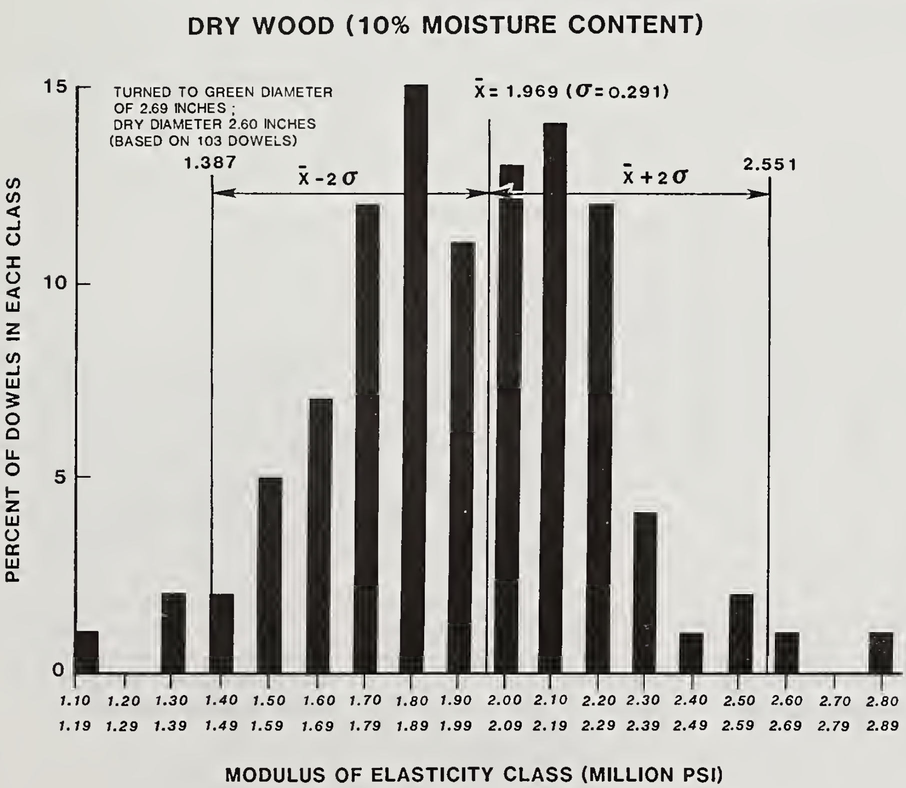

Figure 4-3—Distribution of values of modulus of elasticity at 10 percent moisture content for dowels turned green to a diameter of 2.69 inches. The dowels were turned from lodgepole pines sampled in the Miller Creek drainage about 25 miles east of Libby, MT.

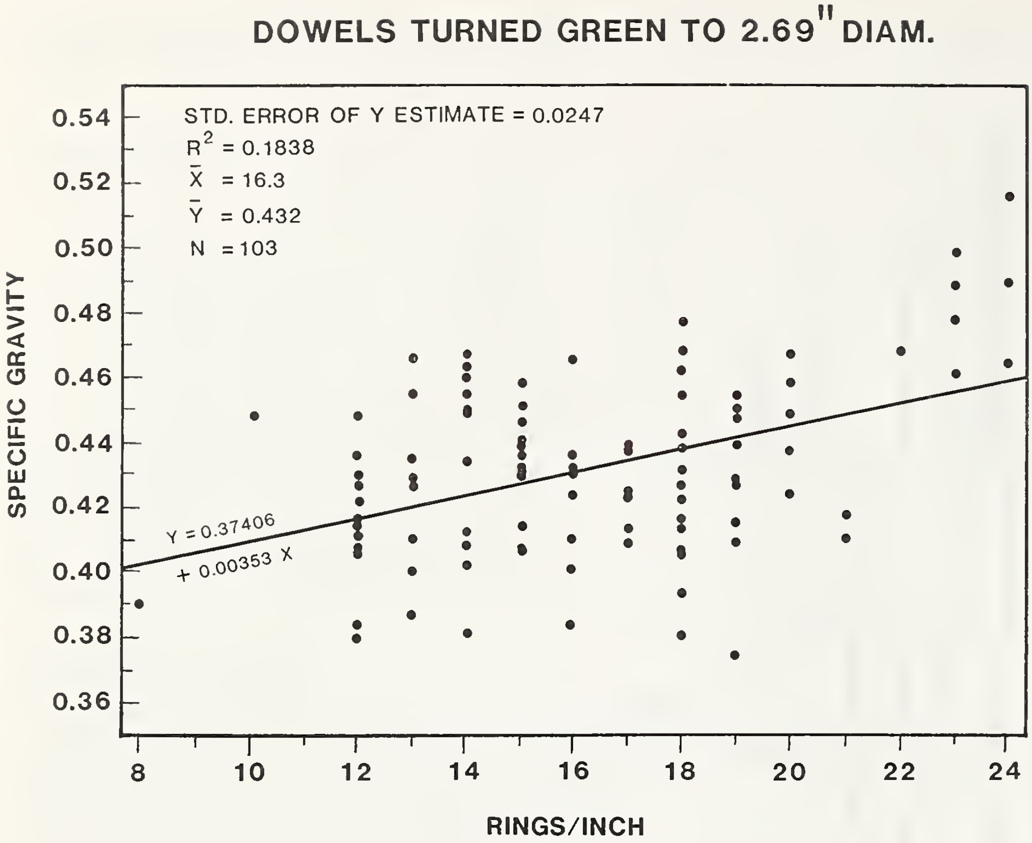

Figure 4-4—Rings per inch in dowel ends related to dowel specific gravity (based on oven-dry weight and green volume). The lodgepole pines from which the dowels were machined were sampled in the Miller Creek drainage east of Libby and turned green to 2.69 inches in diameter.

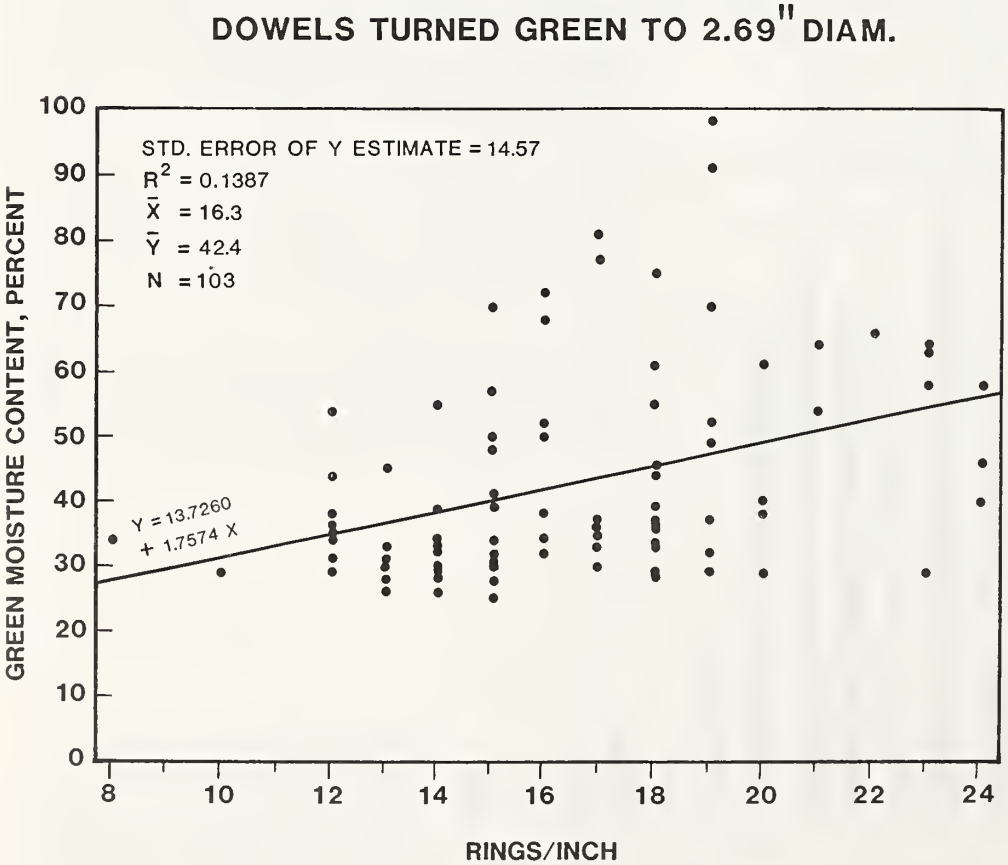

Figure 4-5—Moisture content (percentage of ovendry weight) of green 2.69-inch-diameter lodgepole pine dowels related to rings per inch in dowel ends. Trees from which the dowels were turned were cut in the Miller Creek drainage east of Libby, machined the next day in Missoula, MT, and the green moisture content determined in the laboratory the following day. Some water content was lost during the 50-mile transport from Missoula to the laboratory.

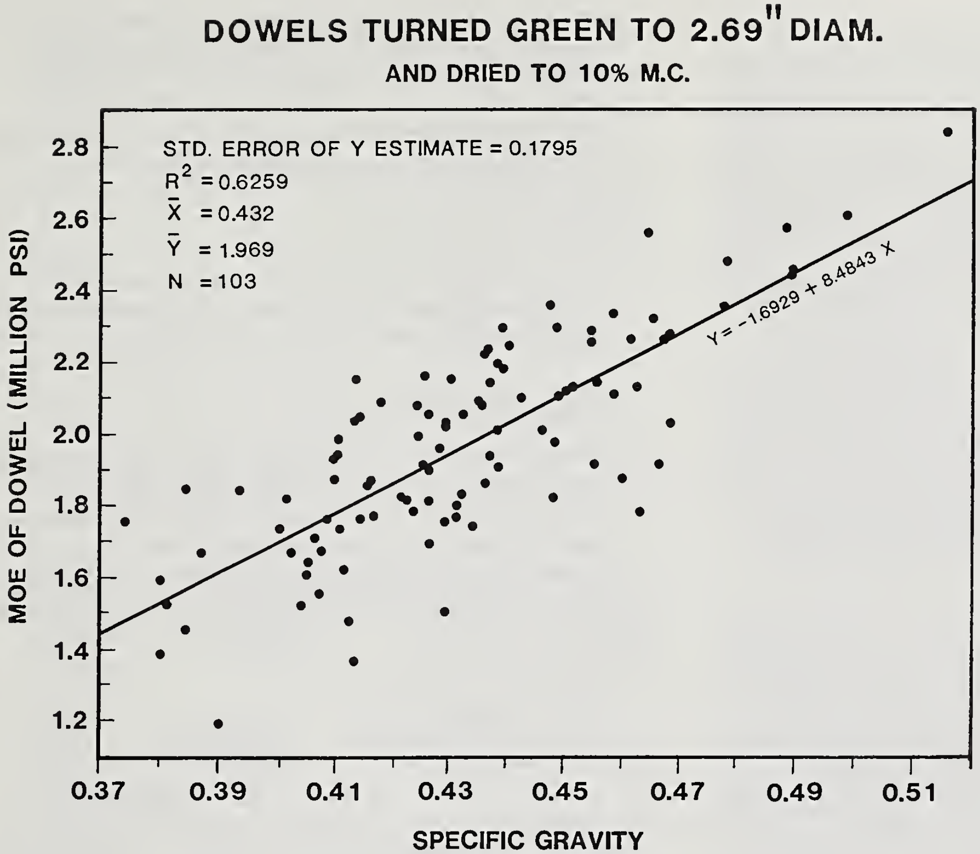

Figure 4-6—Modulus of elasticity of pith-centered lodgepole pine dowels (at 10 percent moisture content) from the Miller Creek drainage turned green to 2.69 inches in diameter related to dowel specific gravity (based on green volume and ovendry weight).

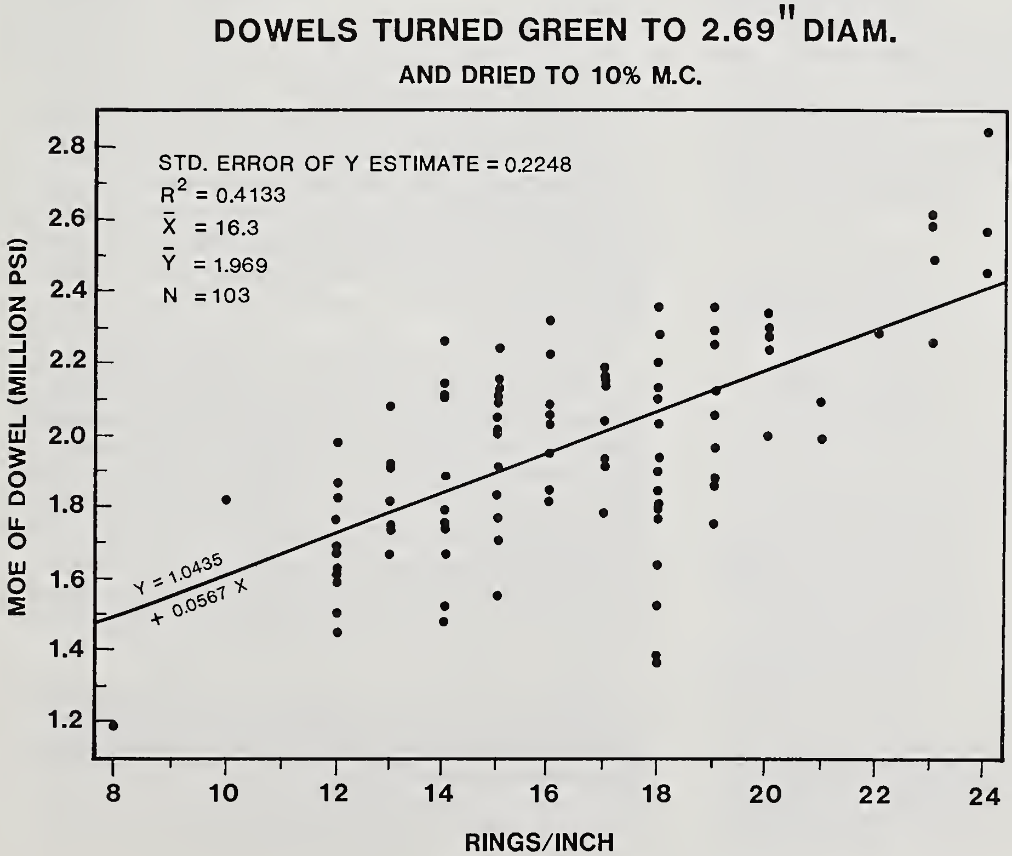

Figure 4-7—Modulus of elasticity of pith-centered lodgepole pine dowels (at 10 percent moisture content) from the Miller Creek drainage turned green to 2.69 inches in diameter related to the average number of rings per inch in the two dowel ends.

Specific Gravity

Throughout the full latitudinal range of lodgepole pine (var. *latifolia*) from 40 to 60 degrees, entire stemwood of trees measuring 3, 6, and 9 inches in diameter at breast height has specific gravity averaging 0.43, 0.42, and 0.41, respectively, based on ovendry weight and green volume. Specific gravity of such trees increases with increasing latitude from south to north up to the Canadian border, and is then more or less constant to 60 degrees (appendix fig. III-9; Koch 1987). Thus, lodgepole pines in Montana have near-maximum specific gravity for the species.

Ten lodgepole pine trees 4 to 4½ inches in d.b.h. sampled by Koch and Barger (1988) from the Kootenai, Flathead, Deerlodge, Gallatin, and Helena National Forests in Montana had average stemwood specific gravity of 0.492. This value was obtained from disks taken at 20 percent of tree weight—height at which specific gravity is close to the entire stemwood average—and is based on ovendry weight and volume at 8.2 percent moisture content.

Burke and Koch (1987) and Koch and Burke (1988) found that 16-foot-long dowels turned when green to diameters of 2¼, 2½, and 2.69 inches had specific gravities of 0.42, 0.43, and 0.43, respectively (based on ovendry weight and green volume). Trees from which the 2¼ and 2½-inch dowels were turned were sampled from three locations in the Libby to West Glacier area of northwestern Montana. Those turned 2.69 inches in diameter came from the Miller Creek drainage about 25 miles east of Libby, MT. Dowel properties are summarized as follows:

Statistic (average values)	Green dowel diameter, inches: 1¼	2½	2.69
Number of dowels evaluated	76	76	103
Specific gravity (based on ovendry weight and green volume)	0.42	0.43	0.43
Moisture content when green, percent of ovendry weight	61.9	58.4	42.4
Diameter shrinkage (green to about 10 percent moisture content), inch	0.10	0.10	0.09
Sweep in 16-foot lengths, inch			
When green	0.80	0.60	—
When at 10 percent moisture content	0.80	0.70	—
Modulus of elasticity measured in flexure over a 15-foot span with center-point loading, million lb/in²			
When green	1.446	1.553	—
When at 10-percent moisture content	1.739	1.850	1.969
Weight per lineal foot at 10-percent moisture content, pounds	0.78	0.98	1.17
Grain angle at dowel surface, degrees	1.40	1.50	2.3
Rings per inch	—	—	16

Stemwood specific gravity diminishes from stump height to treetop. For Montana lodgepole pines 3 to 9 inches in d.b.h. in the Libby-Troy latitude, stemwood values in the upper tree will likely average about 0.40 based on ovendry weight and green volume; at stump height the average will be near 0.47 (appendix figs. III-10 and III-11; Koch 1987).

Dowel specific gravity is positively correlated with rings per inch averaged from both dowel ends (fig. 4-4).

Moisture Content

Dowel moisture content is positively correlated with dowel rings per inch (fig. 4-5). Because heartwood content of dowels is high, moisture content is relatively low.

Modulus of Elasticity

These dowels turned from trees sampled in the Libby to West Glacier area and in the Miller Creek drainage of northwestern Montana had average modulus of elasticity values (nondestructively evaluated in flexure over a 15-foot span with center-point loading) as shown in the foregoing tabulation, with distribution of values as depicted in figures 4-1, 4-2, and 4-3. The standard deviations and ranges were as follows:

Dowel green diameter, inches and moisture content at test	Standard deviation	Range
	- - - - Million lb/in² - - - -	
2¼ inches		
Green	0.235	0.937-2.026
10 percent of ovendry weight	.262	1.136-2.376
2½ inches		
Green	.195	1.081-1.985
10 percent of ovendry weight	.251	1.322-2.460
2.69 inches		
10 percent of ovendry weight	.291	1.193-2.841

Analysis of the 2.69-inch dowels from Miller Creek indicated that MOE was unrelated to dowel diameter shrinkage between green and dry, or to the grain angle of checks visible in dry dowel surfaces. MOE was, however, positively correlated with dowel specific gravity (fig. 4-6), and with rings per inch averaged from both ends of each dowel (fig. 4-7).

Only five of the 103 Miller Creek dowels turned green to 2.69 inches in diameter had MOE values of less than 1.5 million lb/in² (fig. 4-3). Of the 98 dowels with MOE values of 1.5 million lb/in² or greater, only six had defects (catfaces, large knots, bark inclusions, machine gouges) severe enough to eliminate them from use as joist flanges or other demanding structural use.

Unmachined stem sections have significantly higher MOE than those from which one-fourth or one-half inch of radius has been machined (appendix section III-4; fig. III-3).

Trends in MOE of stemwood from throughout the range of lodgepole pine in North America are discussed in appendix section III-6; in brief, there is a positive correlation between latitude and MOE.

Compression Strength

As with MOE, compression strength parallel to the grain of unmachined stem sections is slightly greater than in sections from which one-fourth or one-half inch of radius has been turned (appendix section III-4 and fig. III-4; Burke and Koch 1986). Therefore, data useful in predicting mechanical properties of dowels must be determined after they have been machined to diameter.

With this in mind, 10 lodgepole pines 4 to $4^1/2$ inches in d.b.h. were sampled from five National Forests in Montana; from each tree, stemwood sections (9 inches long taken to include a knot cluster) were removed at 20 percent of tree height. After drying, but prior to test, the stemwood sections were machined to cylindrical form $2^1/4$ inches in diameter. Properties of these sections in compression parallel to the grain, adjusted to 10-percent moisture content, were as follows:

	Compressive strength		
Statistic	**Ultimate**	**Proportional limit**	**MOE**
	Lb/in²		*Million lb/in²*
Average	7,116	4,928	1.629
Standard deviation	1,048	798	.256
Range	5,910-8,730	3,500-6,080	1.350-2.090

The probability is 95 percent that at least 95 percent of the distribution from which these compression specimens were taken will have an ultimate compression strength parallel to the grain in excess of 4,065 lb/in².

Tensile Strength

For a discussion of the variation in lodgepole pine stemwood tensile strength throughout the North American range of the species, see appendix section III-6.

In brief summary, ultimate tensile strength of pith-centered dowels turned from trees 3 inches in d.b.h. was positively correlated with latitude; when tested at 12 percent moisture content these dowels $2^1/4$ inches in diameter—and containing knot clusters—had average ultimate tensile strength of 5,158 lb/in².

Straightness

Stems of lodgepole pine from Montana forests are straighter than those of most conifers. When doweled, the sweep in 16-foot lengths will probably average about 0.7 inch when green, with range up to 2.5 inches and standard deviation of 0.4 inch. When dried to 10 percent moisture content, the dowels will probably have average sweep of 0.7 inch, with standard deviation of 0.3 inch and range up to about 2 inches. Sweep will be slightly less in large-diameter than in small-diameter dowels.

Permeability

Because tree props are imbedded in the ground during use, they are usually treated with preservatives to inhibit decay. One of the most useful indicators of the treatability of wood with liquid preservatives is permeability by gas.

Hofmann (1986) examined the gas permeability of lodgepole pine stemwood specimens sampled from throughout the major latitudinal and longitudinal range of the species. The specimens—both heartwood and sapwood—were taken from about 10 percent of tree height and evaluated when at a moisture content of 13 percent of ovendry weight. Hofmann's measurements showed that the sapwood of lodgepole pine has permeability corresponding to the lower third of the permeability range for southern pine (an easily treated species), indicating a reasonably good treatability of the wood with liquids. Unlike southern pine, however, lodgepole pine has a fairly high heartwood content—especially in trees of small diameter. Since the heartwood of lodgepole pine is approximately 10 times less permeable than its sapwood, tree props comprised mostly of heartwood are difficult to impregnate with liquid preservatives. Permeability of sapwood and heartwood were unrelated to elevational zone, latitude, or longitude—except as these factors influenced the proportion of heartwood in the specimens. Trees 3 inches in d.b.h. had heartwood that was more permeable and sapwood that was less permeable than comparable tissues in trees 6 and 9 inches in d.b.h.

In spite of the impermeability of its heartwood, lodgepole pine tree props are favored in the market because of their strength, straightness, and light weight. For use in some adverse climates, however, it would be wise to incise props comprised mostly of heartwood, thereby increasing preservative penetration and retention.

Summary Statistics on Miller Creek Dowels

To conclude this section on dowel properties, following are some summary statistics on 103 16-foot-long pith-centered dowels from lodgepole pines sampled about 25 miles east of Libby, MT, from the Miller Creek drainage. These dowels were turned green to 2.69 inches in diameter and air dried to 10.17 percent moisture content (range 9.09 to 11.25 percent).

Property	Average	Standard deviation	Range
Moisture content when green, percent	42.4	15.5	25-98
Specific gravity based on ovendry weight and green volume	0.432	0.027	0.374-0.515
Weight per lineal foot when ovendry, pounds	1.07	0.07	0.91-1.28
Rings per inch	16.3	3.3	8-24
Maximum grain angle evident from drying checks, degrees	2.3	1.6	0-7
Diameter when air dry, inches	2.60	0.01	2.56-2.63
Diameter shrinkage from green to air dry, inch	0.09	0.01	0.07-0.12
Modulus of elasticity, million lb/in²	1.969	0.291	1.193-2.841

4-2 FABRICATED JOISTS

Properties of the joists (fig. 3-2) are compared to those of competitive products in table 3-3, and summarized from appendix section III-12 as follows:

Property	Fabricated joist depth (fig. 3-2)			
	10 inches	12 inches	14 inches	16 inches
Depth, inches	10	12	14	16
Weight per lineal foot at 10-percent moisture content, pounds	2.9	3.1	3.3	3.5
EI, million inch² pounds	253	387	516	636
Maximum resistive moment at 100 percent of design load, foot pounds	7,096	9,333	11,595	13,871
Maximum vertical shear load at 100 percent of design load, pounds	946	1,000	1,000	1,000

The correlation between the modulus of elasticity of the dry dowels used to make the flanges and the EI of the joists (appendix fig. III-17) is not particularly strong (R^2 = approximately 0.5); that is, only about 50 percent of the variation in EI of the joists (EI is a measure of joist stiffness) is explained by the modulus of elasticity of the dry dowels used as flanges in the joists. Tests comparing the modulus of elasticity of the flange dowels before and after machining the slot for the web and flats on three sides (appendix fig. III-16 and appendix table III-5) suggest that this machining significantly reduces flange modulus of elasticity and probably accounts for the poor correlation observed.

The correlation between the modulus of elasticity of the dry dowels and the ultimate resistive moment of the joists (a measure of load carrying capacity) is weak (R^2 = approximately 0.2); that is, only about 20 percent of the variation in ultimate resistive moment of the joists is explained by the modulus of elasticity of the dry dowels used as flanges in the joists (appendix fig. 111-18).

Both EI of the joists and ultimate resistive moment of the joists are poorly correlated with visual grade of the dowels used as flanges for the joists. Apparently bark inclusions, drying checks, and even moderately coarse knot clusters in the flange dowels do not have a powerful negative effect on EI and ultimate resistive moment of the joists. For this reason, the finger joints in the flanges—if well made—should not strongly affect the mechanical properties of the joists.

More important is the quality of the web and of the glue joint between flanges and web; interlaminar web shear adjacent to these joints is one of the major failure modes of the joists (appendix fig. III-21; appendix table III-8). When flanges break (rather than the web), the failures are sometimes in compression, but more frequently in tension.

Appendix III traces development of the pole joist and gives additional data on the physical and mechanical properties of such joists.

4-3 EDGE-GLUED LUMBER PANELS

As noted in section 3-2, the edge-glued panels (fig. 3-5) will be manufactured in a range of thicknesses (3/4 inch through 2 1/2 inches), lengths up to 96 inches, and widths up to 48 inches. Only wood with sound, small knots will be incorporated in the panels. Panels will be sanded on both sides and cut to size as required by the market.

The panels are intended for decorative woodwork, rather than for structural applications, so—while they will have the good mechanical properties consonant with their specific gravity of about 0.43 based on ovendry weight and green volume—strength is not of primary importance. Attractive appearance when given natural finishes, good machinability, and acceptable dimensional stability are the primary requisites of the panels.

Lodgepole pine machines readily and lacks the large, difficult-to-machine knots characteristic of some of the other pines used for millwork. The panels will be shipped at a moisture content (8 percent of ovendry weight) calculated to be about equal to that they will attain in service, thereby reducing problems from transverse shrinkage.

Wiedenbeck (1988) measured the shrinkage characteristics of stemwood—at 10 percent of tree height—from the 243 *latifolia* trees collected by Koch (1987) from 40 through 60 degrees latitude in North America. She found that specific gravity (based on ovendry weight and green volume) was linearly related to radial and tangential shrinkage from green moisture content to ovendry according to the following relationships:

Radial shrinkage in mixed sapwood and heartwood, percent $= 11.952G - 0.140$

Tangential shrinkage, percent $= 4.310G + 5.902$

The foregoing equations accounted for 46.6 percent of the variations observed in radial shrinkage, but only 3.7 percent of the variations observed in tangential shrinkage.

These relationships suggest that at a specific gravity of 0.43, radial shrinkage across mixed heartwood and sapwood will average about 5.00 percent, while tangential shrinkage of sapwood will average about 7.76 percent. Because of the nature of construction of the edge-glued panels (fig. 3-5), their width shrinkage should be intermediate between these two values, that is, about 6.4 percent from green to ovendry. Therefore, width shrinkage of these panels should be about 0.25 percent for each change of 1 percent moisture content from that at which shipped. For example, a panel measuring 10.0 inches wide when shipped at 8 percent moisture content will expand to about 10.025 inches in width if placed in service at 9 percent moisture content, and to about 10.100 inches if placed in service at 12 percent moisture content. Conversely it will shrink to 9.950 inches in width if in service at 6 percent moisture content.

Shipping weight should be about 31 lb/ft³.

4-4 ORIENTED-STRAND BOARD

The major portion of the wood content of the OSB panels will be lodgepole pine and a lesser portion other species, principally Douglas-fir, larch, and subalpine fir

(section 5-8 and table 5-1). The board will have an ovendry weight of about 41 lb/ft³ and a shipping weight (at 8 percent moisture content) of about 44.2 lb/ft³.

Flakes in panel faces will be aligned at 90 degrees to core flakes (fig. 3-6). Flakes cut 3 inches long with target thickness of 0.020 inch—after removal of extreme fines for fuel—will be screened so that the narrower flakes will be in the core and the wider flakes in the face layers (fig. 5-11).

With about 5 percent content of phenol-formaldehyde resin and wax, and moisture content at test of about 8 percent, the OSB in sheathing thickness (7/16-inch) should have mechanical properties about as follows:

Property	Direction of test: Parallel to face flake alignment	Direction of test: Across face flake alignment
	Lb/in²	
Modulus of elasticity	1,200,000	300,000
Modulus of rupture	7,000	3,000
Internal bond strength	90	

Quality control will ensure that the OSB products manufactured meet the American Plywood Association (1980) performance standards for sheathing and for combination subfloor and underlayment.

Flakeboard for Webs in Fabricated Joists

The flakeboard produced for internal consumption as webs in fabricated pole joists will not be OSB, but will have random orientation of flakes in all layers. Such random arrangement enhances in-plane shear strength of the webs. Also, the web flakeboard will be somewhat denser than the OSB sheathing product. Additionally, special emphasis will be placed on tightly bonding face flakes in these webs to enhance interlaminar shear strength adjacent to the web-flange joint.

4-5 ORIENTED-STRAND LUMBER

As noted in sections 3-2 and 5-8, the forming heads preceding the hot press (figs. 5-11 and 5-12) will be designed to permit mat formation with all flakes in all layers parallel to the 32-foot length of the press, thus permitting manufacture of 32-foot-long, 1.5-inch-thick, oriented-strand structural lumber from the same flakes utilized in the manufacture of OSB sheathing and floor panels.

The technology of making structural lumber from such flakes is in the early stages of development, but it seems likely that it will soon become practical to manufacture 1.5-inch-thick oriented flake composite (wood and adhesive) lumber with property values—at 10 percent moisture content—as follows (at a specific gravity of not more than 0.67 based on ovendry weight and volume at 10 percent moisture content):

Property	Average	Standard deviation	Range
		Lb/in²	
Modulus of elasticity	1,400,000	180,000	1,000,000-1,800,000
Modulus of rupture in edgewise bending	7,600	1,000	5,000-10,000
Compression parallel to the grain; that is crushing strength	5,250	400	4,250-6,250
Tensile strength parallel to the grain	3,500	400	2,500-4,500

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CHAPTER 5: PLANT LAYOUT, POWER, AND STAFFING REQUIREMENTS

CONTENTS

5-1 CHARACTERISTICS OF INCOMING WOOD

The plant (fig. 3-8; section 2-6) must receive, store, and process annually 240,000 tons of trees and logs—predominantly lodgepole pine—yielding 200,000 tons of stemwood, 20,000 tons of stembark, and 20,000 tons of branches (ovendry-weight basis). As discussed in section 3-3, products shipped will total 133,610 tons annually (wood content only, ovendry-weight basis) and will include tree props, fabricated joists, oriented-strand board and possibly oriented-strand lumber, edge-glued panels, 2 by 4 studs, pulp chips, and particleboard furnish; additionally, about 85,503 tons of residue for internal use as fuel will be generated annually during manufacturing operations (ovendry-weight basis).

Trees received at the plant will enter in two forms. The major portion of the wood entering the plant (yielding 110,000 tons, dry basis, of stemwood annually) will be in the form of whole, predominantly sub-sawlog-size lodgepole pine trees from National Forest lands. As much as one-fifth of this incoming tonnage, but probably a lesser proportion, will be from dead trees. All of these trees, both live and dead, will be severed at stump height and trucked, with branches attached, to the plant. Mixed in with the lodgepole pine trees will be some trees—probably 5 to 10 percent by weight—of other species, mostly Douglas-fir, larch, spruce, and subalpine fir. Butt diameters of the lodgepole pine trees will measure not less than 3 inches outside bark; an occasional tree might exceed 24 inches at the butt, but only about 4 percent will exceed 14.9 inches in breast-height diameter. About 90 percent of these trees from National Forest lands will have breast-height diameters in the range from 3.0 to 7.9 inches (table 2-4). Lodgepole pine stem lengths from stump top to apical tip and to a 2-inch top diameter inside bark, and average branch diameters should be about as follows (table 2-5):

Tree d.b.h.	Stem length to apical tip	Stem length to 2-inch top	Average branch diameter near stem
Inches	- - - - - *Feet*	- - - - -	*Inches*
3	30.5	16.5	0.35
6	51.2	39.1	.51
9	62.5	52.9	.75

A lesser amount of wood (yielding 90,000 tons annually of stemwood, ovendry-weight basis) will enter the plant in the form of tree-length logs of various coniferous species purchased on the open log market. Lodgepole pine logs will predominate, but significant proportions of Douglas-fir, larch, spruce, and subalpine fir will be included. Minimum top diameter inside bark will be 4.5 inches; butt diameters will be specified not to exceed 16 inches. Average butt diameter will probably be about 10 inches. Only logs cut from live trees will be accepted.

Regardless of wood source, no tree or log admitted to the plant will exceed 50 feet in length (generally they will be less than 40 feet), and none will be shorter than 8 feet.

Numbers of Trees Processed Annually

From National Forest Lands—The ovendry weight of stemwood from stump top to apical tip averages 20.2, 130.4, and 339.7 pounds for North American lodgepole pine trees measuring 3, 6, and 9 inches in d.b.h. (Koch 1987). From these data it can be inferred that trees 4, 6, and 8 inches in d.b.h. should have stemwood weights of about 43, 130, and 250 pounds, ovendry-weight basis.

From table 2-4, and the foregoing discussion, it is concluded that almost all the lodgepole pines to be drawn from the National Forest lands are in the 4-, 6-, and 8-inch diameter classes, in approximately the following proportions by numbers of trees:

D.b.h. class	Numbers of trees in Flathead, Lincoln, and Sanders Counties	Ratio (fraction) compared to d.b.h. class of 4 inches
Inches		
4 (3.0-4.9)	169,747,337	1.000
6 (5.0-6.9)	146,699,540	.373
8 (7.0-8.9)	77,307,764	.196
Total	393,754,641	

As 110,000 tons of stemwood, ovendry, will be harvested as whole trees from National Forest lands annually, it is possible to use the foregoing data to solve for the number of stems in the 4-, 6-, and 8-inch diameter classes comprising this 110,000 tons, as follows (where N = the number of 4-inch-class stems):

$$(110{,}000)(2{,}000 \text{ pounds}) = 43N + 130(0.373N) + 250(0.196N)$$

It follows, therefore, that the 110,000 tons of stemwood (predominantly lodgepole pine) harvested annually as whole trees from National Forest lands will be comprised as follows:

Tree d.b.h. class	Number of trees annually
Inches	
4	1,565,948
6	584,099
8	306,925
Total	2,456,972

Purchased on the Open Log Market—If the 90,000 tons of stemwood (ovendry basis) purchased annually on the open log market were specified to have a minimum top diameter of 4.5 inches inside bark and the average butt diameter was 10 inches, with inside-bark taper of 1.25 inches per 100 inches of stem length, average log length should be about 37 feet. Stemwood volume per log would therefore average about 10.6 ft^3, and ovendry stemwood weight should be about 300 pounds per log.

These data suggest that the component of wood purchased on the open log market should total about 600,000 logs annually.

5-2 SCALING, STORAGE, AND RETRIEVAL OF INCOMING WOOD

As previously noted, annual intake of wood will consist of about 2,456,972 whole trees cut from National Forest land (mostly 3 to 9 inches in diameter at the butt), and about 600,000 purchased logs (with top diameter of $4^1/2$ inches and butt diameters averaging 10 inches and not exceeding 16 inches). These 3,056,972 trees and logs will be random length from 8 to 50 feet, but most will measure less than 40 feet in length.

Scaling

All incoming truckloads of whole trees and logs will be green-weight scaled, with payment based on estimated load content of ovendry stemwood weight.

Storage of Trees and Logs

Trucks will be unloaded with a portal crane (figs. 5-1 and 5-2). Offloaded whole trees and logs will be stacked separately in high decks under the portal crane. To the extent possible, the whole trees will be separated under the crane into piles of live lodgepole pine, dead lodgepole pine, and live trees of other species. The decks will be of sufficient capacity to store trees and logs adequate for 80 days of plant operation. A spray system designed to water-wet the decks during summer will be provided to suppress growth of blue-stain fungi in the stored wood.

The portal crane will move wood from storage to the infeed decks of the delimbers and debarkers. Whenever possible, however, the infeed decks will be served directly from incoming trucks.

Lodgepole pine logs and whole trees harvested in the Libby-Troy area should have moisture contents near the average (about 100 percent of ovendry weight) for the species in North America (Koch 1987, figs. 2-3 and 2-12). The annual intake of 240,000 tons of wood and bark (ovendry basis) is therefore equivalent to about 480,000 tons on a green basis.

If incoming trucks average 26 tons of green wood and bark per load, it follows that the portal crane must annually unload about 18,462 trucks. If wood is received 50 weeks per year, 369 trucks must be unloaded weekly. More likely, wood receivals will be restricted because of weather or road conditions to about 40 weeks per year, necessitating an average of 462 trucks weekly during the 40 operating weeks. If weight scaling and offloading are restricted to two 8-hour shifts 5 days per week during

each of the 40 operating weeks, about 46 loads must be offloaded per shift.

The green weight of purchased logs (wood plus bark) will average about 660 pounds each. The whole trees harvested from National Forest lands will have average green weight (wood plus bark and some foliage) of about 215 pounds each. On average, each truckload will therefore contain about 79 tree-length logs purchased on the open market, or about 215 whole trees of small diameter harvested from National Forest lands.

If 26-ton truckloads of incoming wood average 8 feet wide by 10 feet high, with maximum tree or log length of 50 feet, then an 80-day supply of wood (4,046 truckloads) will occupy decks 50 feet wide, 50 feet high, and 6,474 feet long. With main span of 165 feet, and 60 feet of cantilevered span on both ends, a total of five decks can be built (three under the main span—the center one arranged with stems parallel to the crane tracks, and one under each cantilevered end); thus the length of the craneway for storage purposes (not including space for offloading trucks, some log sorting, and space for infeed log decks feeding the delimber and debarker) should be about 1,295 feet long. To provide space for truck offloading, and for infeed decks (plus a little surplus storage), the proposed craneway is 1,500 feet long (fig. 5-2). In these decks, butts of logs and trees in each grapple load will all be oriented in one direction; brow logs strategically placed by the crane-grapple operator will facilitate this arrangement.

A crane-grapple payload capacity of 20 tons will permit quick loading of infeed decks, and will permit unloading of each log truck in two lifts. Available lift height under the grapple will be 55 feet, with lift speed of 50 ft/min, trolley speed (transverse to tracks) of 350 ft/min, and traverse speed along the crane tracks of 500 ft/min.

Connected power on the portal crane will total 340 hp: 150 hp on the hoist, two 15-hp motors on the trolley, two 50-hp motors to traverse the crane, and one 60-hp motor on the grapple.

The trolley and girder will have lights for night operation.

Figure 5-1—Portal crane with 20-ton lift capacity capable of offloading a log truck in two lifts. In the proposed plant the main span will be 165 feet and the two cantilevered end spans will each measure 60 feet. Clearance under the grapple will permit log storage to 50 feet high. (Photo from Harnischfeger Corporation.)

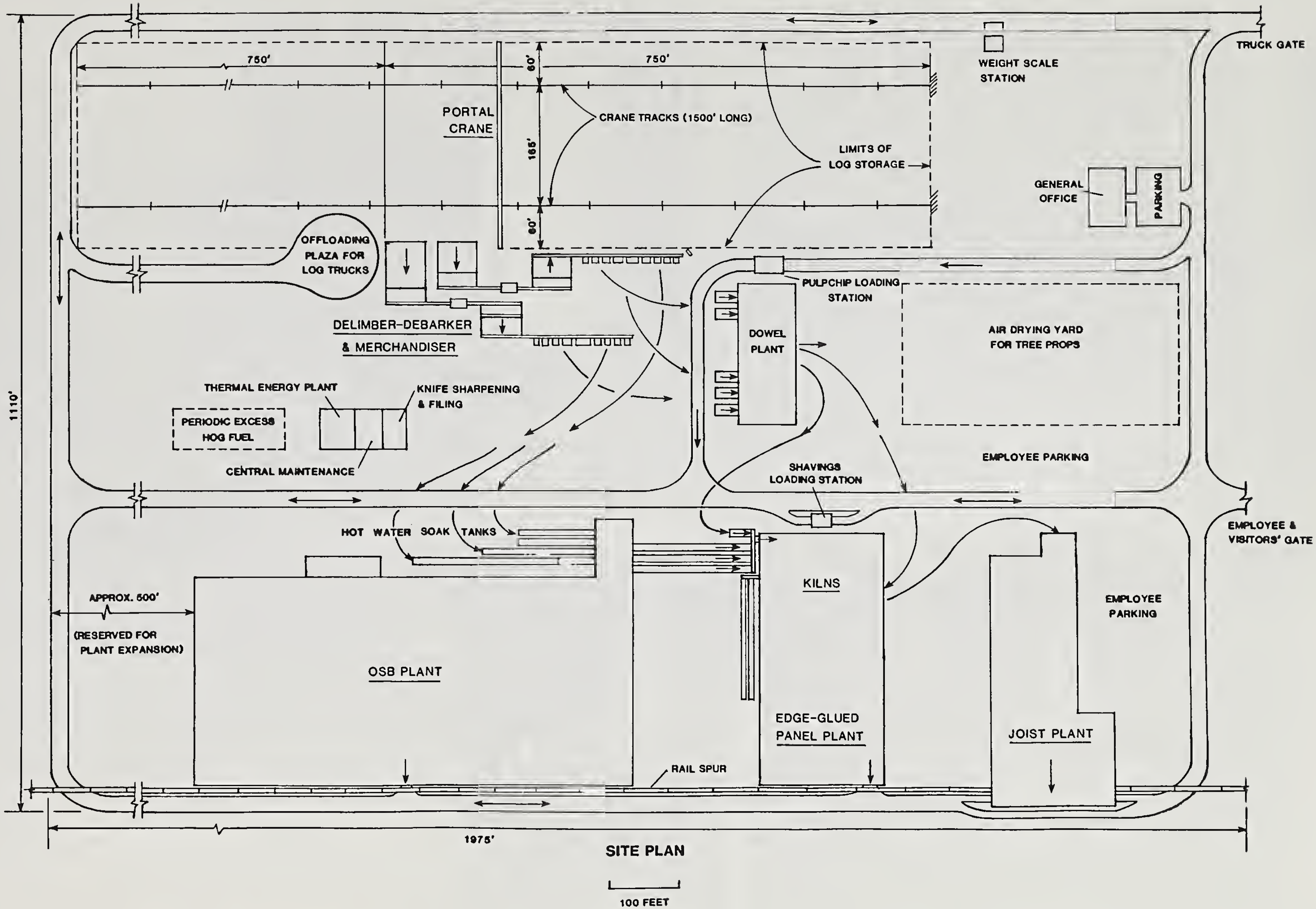

Figure 5-2—Site plan showing relationship of portal crane to the rest of the operation. Arrows from merchandiser indicate general directions of material flows.

Retrieval

The portal crane will service two infeed decks (fig. 5-3), both receiving more or less the same mix of all incoming wood—including lodgepole pine (both live and dead) and non-lodgepole pine. As noted previously, the total number of stems entering the plant annually will be 3,056,972 or 6.07 stems per minute for 350 24-hour days annually. If it is assumed that delimbing, debarking, and stem bucking activities are functional ("up" in the vernacular) 80 percent of the time, deck and machine rates must be set to accommodate a total of 7.6 stems per minute, that is, 3.8 stems per deck per minute.

Of this 7.6 stems per minute, 19.6 percent will be purchased wood with no limbs. Such logs will have a minimum top diameter of about $4^1/2$ inches and will average about 37 feet long with butt diameters averaging about 10 inches. Most of these stems will be 16 to 40 feet long, but the full length range will be 8 to 50 feet.

Of the total of 7.6 stems per minute, 80.4 percent will be whole trees with most limbs attached—mostly lodgepole pine (perhaps 5 percent non-lodgepole). About 25 percent of these lodgepole pines will have been harvested from beetle-killed stands. Top diameters will be about $1\text{-}^1/2$ or 2 inches, and length will average 34 feet, with most stems 16 to 40 feet long but with full range of 8 to 50 feet.

In an average 24 hours of operations, a total of about 10 logs with butt diameters exceeding 16 inches will be loaded on the two decks (logs too large to be processed); the rest of the logs will be smaller.

Each deck will be equipped with an extendable-reach, manned, hydraulic grapple. A minor function of these grapples will be to deposit logs with butt diameters in excess of 16 inches on portal-crane-accessible bunks for later manual bucking to yield stem sections smaller than 16 inches and larger butt sections for resale. The principal task of each hydraulic grapple will be deposition of 3.8 stems per minute (average) into a conveyor feeding a delimber-debarker.

5-3 DELIMBING AND DEBARKING

Delimbing

As reported by Kwasnitschka (1978), equipment has been in satisfactory service for a decade that will delimb whole trees of the dimensions just described at a maximum feed rate of 131 ft/min. In these operations (in Germany), the delimber is closely coupled to a mechanical ring debarker. Trees are grapple-loaded and fed butt-end first. In the proposed operation, one such delimber-debarker combination could be fed by each of the infeed decks just described. Alternatively, strap-type delimbers in common use on mobile harvesters could precede the debarkers.

Because of the small top diameters of stems in the proposed operation, it will not be practical to have speedup conveyors preceding the delimbers (as the stems would overrun each other). With infeed conveyor, delimber (and closely coupled debarker) feeding at a constant rate, it will be necessary to space the stems as they are introduced to the conveyor leading to the delimber. With stems averaging about 35 feet long, and with average gap between stems of 5 feet, conveyor speed—and hence delimber and debarker feed speed—must be about 152 ft/min.

As noted previously, about one-fifth of the stems will have been previously delimbed (the purchased wood) and will simply pass through the delimber enroute to the debarker.

Not shown in figure 5-3 is the drum chipper (fig. 5-4) specifically designed to reduce residual branches and bark to fuel particles. This chipper has a 9-foot-wide infeed conveyor delivering the branches and bark through infeed crusher rolls to a 48-inch-diameter by 64-inch-long drum chipper.

Debarking

A mechanical ring debarker will be closely coupled to each delimber and will feed at the same lineal rate. Most ring debarkers cannot remove bark from stems smaller than $2^1/2$ inches. So some bark will likely be left on many of the stem tops. Most of this small-diameter wood is to be dowelled, thus the residual bark will be removed in the dowelling process. Residue from the dowelers is unsuitable for pulp or flakeboard and will be used as fuel.

The feedworks of the ring debarker must be able to accommodate the full range of stem diameters from $1^1/2$ inches to 16 inches. Because the feed speed will be slow (only 152 ft/min), such accommodation should be practical.

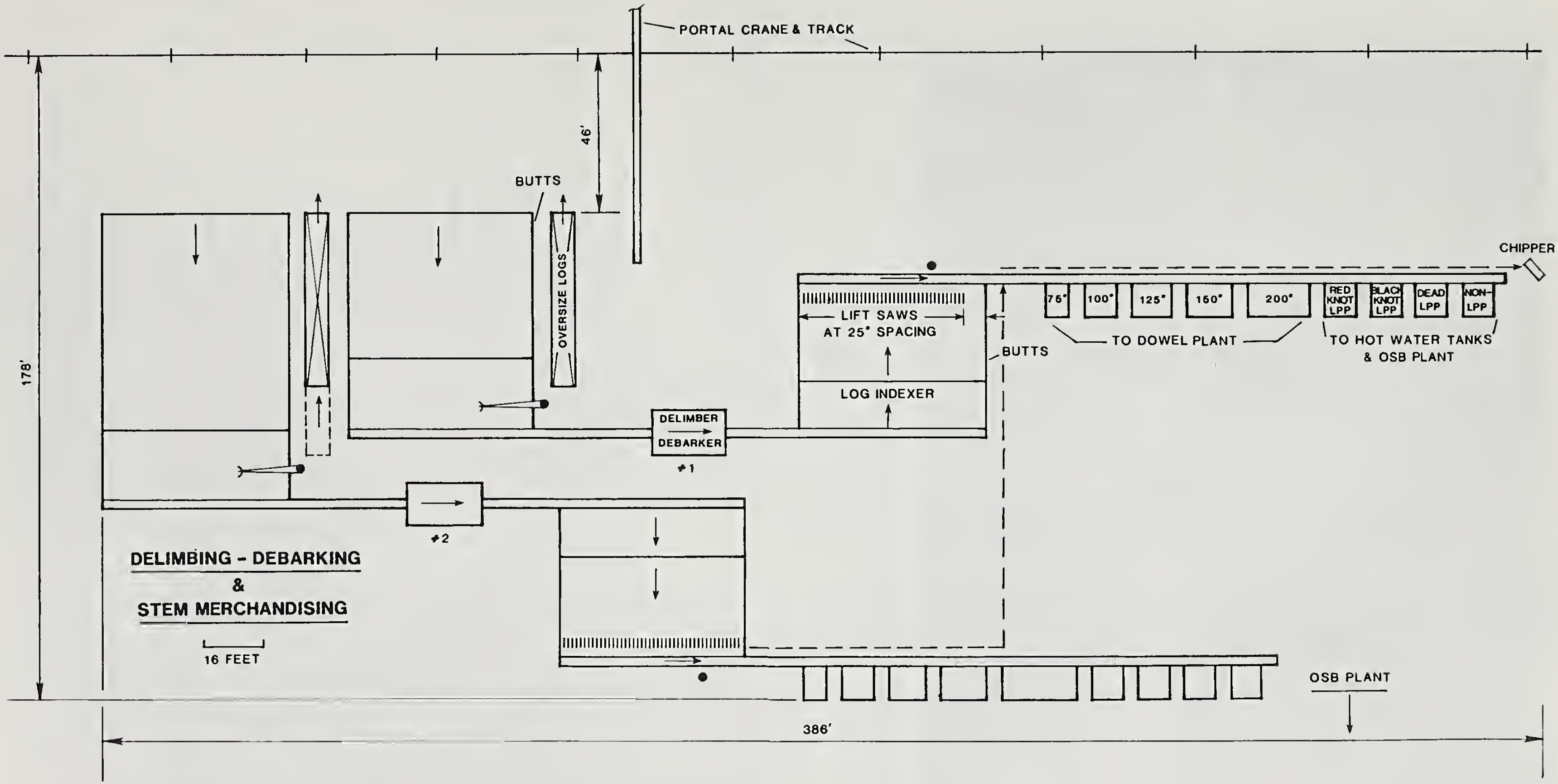

Figure 5-3—Layout of twin infeed decks, delimber-debarkers, and stem merchandisers.

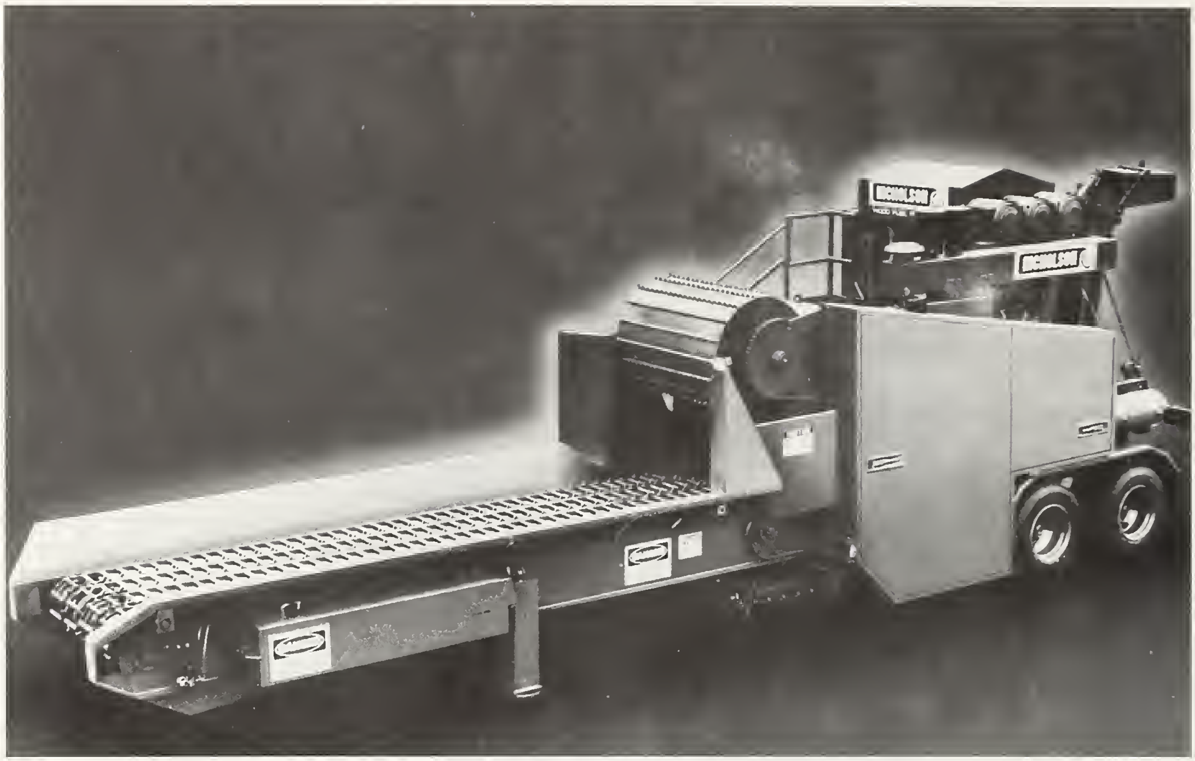

Figure 5-4—Comminution machine carrying a 48-inch-diameter, 64-inch-long drum chipper designed to chip and size branches and bark for hog fuel. (Photo from Nicholson Manufacturing Company.)

5-4 STEM MERCHANDISING

The process of crosscutting a tree stem into sections to maximize stem value is termed merchandising, and the system of machines used for this purpose is called a stem merchandiser. Beginning from the butt of the stem, the sections to be cut from the stem are as follows:

Section description	Diameters: Minimum top	Diameters: Maximum butt	Length
	Inches		
Bolts for disk flaker (OSB) can include shear-shattered butt cuts	4.0	16.0	100
Bolts for edge-glued panels			
4-inch cylinders	4.2	5.5	100
4.5-inch cylinders	4.7	6.0	100
5.25-inch cylinders	5.5	7.0	100
2.625-inch joist flanges	2.8	4.0	200
Tree props (usually 2-inch)	2.1	3.2	75,100, 125, 150
Tops and defects chipped for pulp	random		

The first and last categories in the foregoing tabulation can include all species. The other three categories are restricted to lodgepole pine only. Based on the assumptions made in section 3-2, cutting priorities will be about as follows:

Description of section	Priority
Tree props (usually 2 inches in diameter)	1
Joist flanges	2
Bolts for edge-glued panels	3
Bolts for disk flaker	4
Sections to be chipped for pulp	5

The two stem merchandisers (fig. 5-3) are identical. All products are in lengths that are multiples of 25 inches, so retractable saws are located on 25-inch centers across the width of the transversely moving merchandiser deck. As each stem, previously singulated (positioned individually) on a stem indexer, moves into position to be crosscut, the operator will punch in the sequence of products desired, the appropriate saws will move into the cut, and all severed portions of the stem will fall into a lengthwise conveyor for automatic discharge into the appropriate bins. Operator decisions based on visual grade are required because nonlodgepole pine stems must be reduced to 100-inch lengths for conversion to OSB, while lodgepole pine (both live and dead) can yield tree props, flange dowels, and bolts for edge-glued panels as well as bolts for conversion to OSB. Lodgepole bolts 100 inches long must also be separated into those with sound red knots for edge-glued panels, those with black knots for OSB, and those cut from dead trees for OSB. Additionally, some small-diameter wood is unsuitable for tree props or flange dowels, and must therefore be diverted to bolts for OSB.

As noted previously, with stem merchandiser "up" time of 80 percent, 3.8 stems per minute will be segmented on

each merchandiser. Each operator therefore has about 16 seconds to segment each stem—a time deemed sufficient for the task.

Connected electrical motors on the system of delimbers, debarkers, merchandisers, and chippers will total about 1,200 hp.

Operators staffing the portal crane, log decks, delimber-debarkers, and stem merchandisers are as follows—with all positions occupied 24 hours per day, 350 days per year:

Position	Operators per shift (exclusive of weight scaling and maintenance)
Lead operator	1
Portal crane operator	1
Operators of hydraulic grapples at infeed decks	2
Operators of stem merchandisers	2
Forklift operators transporting stem sections to storage and to appropriate plant infeed decks	2
Total	8

5-5 DOWELING PLANT

Most dowel machines in commercial use operate on the same principle. The stem section to be machined is advanced axially (without rotation) through a rotating knife ring carrying three or four knife-clamp assemblies. These knife assemblies are movable radially to adjust for desired dowel diameter to match an exactly sized collet through which the finished dowel passes. Each of the knife-clamp assemblies carries a roughing knife set to machine a sharp taper, followed by a contiguous finish knife set to machine a shallower taper and establish the desired cylindrical shape (fig. 5-5). The rotating ring that carries the knives is typically powered by a 40 kW motor, and will accommodate dowel diameters from 2 to 7^3/4 inches. Dowelers that can turn 1.5-inch tree props are also available.

Typically, a dowel machine has four pairs of powered, vertically self-centering infeed rolls and three pairs of similar outfeed rolls. Adjustment of the infeed rolls to accommodate stems of varying diameters is accomplished by a control wheel convenient to the machine feeder. Feed speeds available may be as high as 150 ft/min, but few are operated above 50 ft/min if quality of finish on the dowels is important. To prevent flailing of dowels on exit, some operators employ a 12-foot exit tube with a bell-shaped exit end discharging to offbearer or grading chain.

Experienced operators indicate that dry wood machines more readily (and more smoothly) than green wood. Stems machine better in summer than in winter; frozen wood is more difficult to machine than unfrozen. When wood temperature falls below 0 °F, machining is usually impractical.

To maintain feed continuity, stem sections should be accurately classified by diameter (and those with excessive taper diverted) before admitting them to the dowel machines. If stem sections are fed small end first, tree pith will be more accurately centered in the resulting dowel than if fed butt first; but machining problems are lessened (end snipe reduced) if the stem sections are fed butt first.

To maintain surface quality on the dowels, knives should probably be changed after about 4,000 lineal feet have been run. Time required to change knives and set up a machine is seldom less than 30 minutes.

Figure 5-5—This section of a partially machined dowel illustrates the function of roughing knives that produce the tapered cut and finish knives that produce the cylindrical shape. In the plant contemplated, stem sections will be bark free before passing through the dowel machine.

Dowel Plant Output and Machine Layout

As noted in chapter 3, a single doweling machine is capable of running about 2,200 small dowels averaging about 9 feet in length per 8-hour shift (mostly 2 inches in diameter, but some $1^1/2$ inches in diameter). This shortwood machine will be scheduled to run three shifts per day, 350 days per year, on tree props and on small dowels for the edge-glued panel plant. Input of stemwood to this machine will total about 12,798 tons annually, and output will total about 5,146 tons of tree props, 2,955 tons of dowels for the edge-glued panel plant, and 4,697 tons of bark-free residue—all on an ovendry-weight basis (fig. 3-8). This annual tonnage is equivalent to about 2 million 2-inch-diameter props (fig. 3-1) averaging 9 feet long, plus about 280,350 dowels 4 inches in diameter and 100 inches long for conversion to edge-glued panels. The plant layout must accommodate props 6, 8, 10, and 12 feet long. These props will be pointed, banded into packages of convenient size (fig. 5-6), and sold green or air dried, but not kiln dried.

An additional three machines will turn dowels $2^5/8$ inches in diameter for use as flanges in fabricated joists (fig. 3-2). Bark-free stem sections selected for this use will measure 16 feet 8 inches long. Output of each of the three machines should average about 1,000 such stem sections per 8-hour shift—calling for an average feed rate of 35 ft/min sustained over the full 480 minutes of the shift. If machines are operated three shifts per day for 350 days each year, scheduled annual stemwood input will total about 39,632 tons, ovendry-weight basis, with 60 percent ending as dowels and 40 percent as residues. On emergence from the doweling machines, these dowels—all candidates for flanges—will be stacked without sticks in 42- by 42-inch stackable kiln pallets and kiln dried before delivery to the joist plant for stiffness evaluation and further processing. Kilns for these candidate flanges must therefore have an output of 9,000 dowels per operating day, which amounts to an output of about 63,000 dowels per week—assuming 7 days of operation most weeks.

One additional doweling machine—a spare—will discharge onto the flange grading line (fig. 5-7). Thus there will be sufficient machine capacity to permit one doweler to be down at all times for knife change and setup.

All residues from the dowel plant will be conveyed to fuel storage facilities.

Connected power (electrical motors) in the dowel plant is estimated to total 400 hp.

Staffing

The tree-prop machine requires one feeder and one offbearer; the offbearer grades each prop, machines the two ends, and stacks it for banding (fig. 5-6).

Each of the three operating flange machines requires one feeder; all flange machines discharge onto a common grading chain from which one person pulls the dowels into stackable kiln pallets for later forklift transfer into dry kilns (fig. 5-6).

The dowel plant is therefore operated on each shift by four feeders, two offbearers, and one lead operator/setup person. Knifes are sharpened in a filing room central to the entire operation.

Additionally, a forklift operator will require time to service the infeed log decks and transfer loads of packaged tree props to the air drying yard and flange dowels

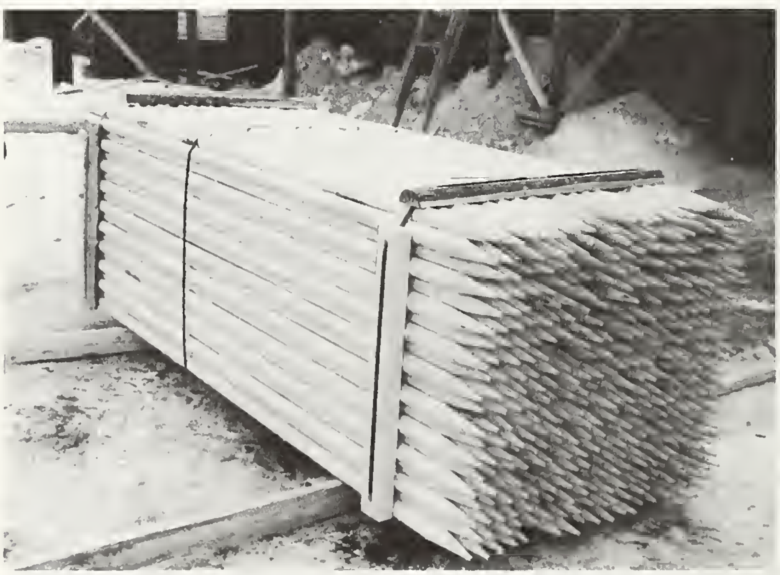

Figure 5-6—Tree props strapped in a package for shipment. To improve package stability, strapping is threaded through holes bored in the ends of each restraining strip.

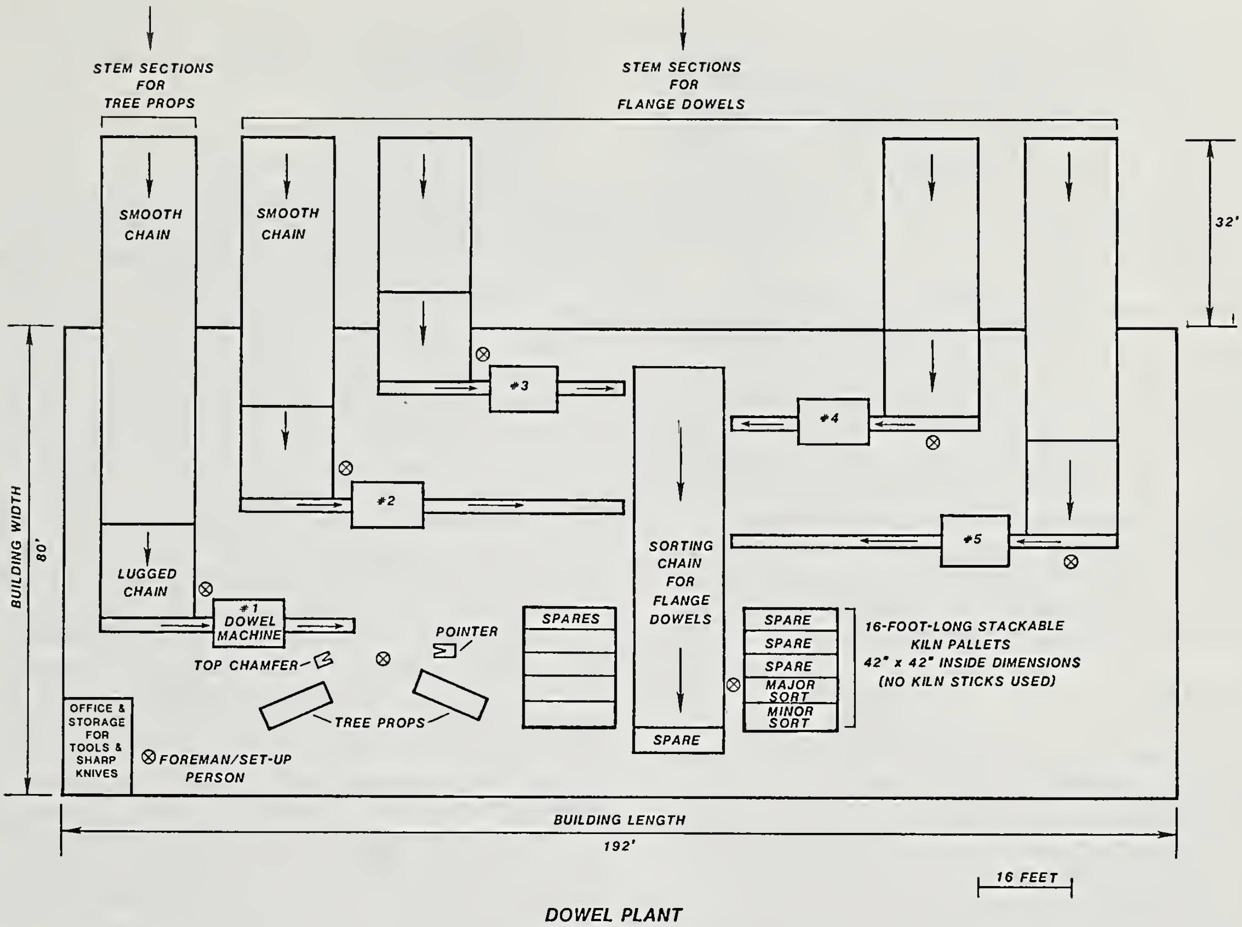

Figure 5-7—Layout of dowel plant housing five doweling machines. Typically, four of the machines will be in operation and one will be down for knife change and setup. When dowel machine #1 is down, tree props can be run on any of the other machines.

to the dry kilns. As noted previously, about 2,200 stem sections suitable for tree props or small dowels for edge-glued panels, and about 3,000 stem sections suitable for flange dowels will enter the dowel plant each shift. Exiting the dowel plant each shift will be about four banded packages of tree props, two forklift units of small dowels for edge-glued panels, and 10 stackable kiln pallets of flange dowels.

5-6 DOWEL KILN AND JOIST PLANT

Dowel Kiln

Gaby (1967) found that 55-inch-long bark-free southern pine roundwood 4 and 5 inches in diameter could be solid-piled without sticks, and kilned at 190 °F (dry-bulb temperature) to 25 percent moisture content in about 2 days. His data indicate that length of piece does not strongly affect time to dry roundwood so piled, with air circulated the length of the roundwood (through the interstices resulting from solid piling the rounds) at 600 to 700 ft/min with periodic reversals. In his experiment, wet-bulb temperature was not controlled, but with vents open throughout the test, the equilibrium moisture content reached a constant level of 3 to 4 percent early in the run.

For manufacture into joists (fig. 3-2), the dowels must be dried to an average moisture content of about 8 percent of ovendry weight, with little variation among pieces; also, moisture gradients within each piece should be minimal. The dowels to be dried in the proposed kilns are only about half the diameter of the roundwood dried by Gaby, and therefore their drying time should be shorter. Lodgepole pine is less permeable than southern pine, however, and this factor will extend drying time. In summary, it seems likely that kiln residence time for a charge of flange dowels will be about 5 days, less a few hours to unload and load the kiln with a forklift. Kiln temperatures should not exceed 190 °F and preferably will be limited to 180 °F to prevent degradation of dowel tensile and compressive strength during drying.

As noted in the last paragraph of section 5-5, the dowel plant will produce about 10 kiln pallets of flange dowels per shift. This amounts to 30 pallets per day and 10,500 pallets per year (because the dowel plant is scheduled to operate 350 days per year). The kiln should operate continuously for 50 weeks per year (350 days), and therefore

must have a holding capacity of 150 kiln pallets—that is, (5 ÷ 350) x 10,500. Because exterior pallet dimensions are about 4 by 4 by 17 feet, and the pallets should probably be stacked three high, the total usable chamber width should be 17 feet and length should be about 200 feet—that is, (150 x 4) ÷ 3. To permit kiln discharge every 2½ days, two chambers each 100 feet long are proposed. Forklift-accessible roofed cooling sheds of about the same dimensions are also required.

In addition to the two dry kilns, a third chamber of equal size—heated to about 90 °F and with air circulating slowly—will be needed to equilibrate dowels pulled, as they enter the joist plant, for redrying (fig. 5-8).

To make the system conveniently operable, numbers of stackable kiln pallets will need to be sufficient for kilns, cooling sheds, and equilibration chamber, and for accumulation of incoming charges and a working inventory in the joist plant. These needs will total about 500 pallets.

Before kiln dimensions are finalized, some research is needed to validate the assumption that dowels 2.625 inches in diameter and 16 feet 8 inches long can be kiln dried to 8 percent moisture content in 5 days.

Joist Plant

As noted previously, each of the three machines turning flange dowels will daily produce 1,000 dowels measuring 16 feet 8 inches in length. Operating 350 days per year, annual output will therefore be 1,050,000 dowels, which when admitted to the joist plant—also running three shifts 350 days per year—must be processed at a sustained rate of 6¼ pieces (105 lineal feet) per minute.

On delivery to the joist plant, the dry candidate flange dowels will be processed as follows:

- Screened for a maximum moisture content of 12 percent; rejects pulled for equilibration to 8 percent.
- Screened for minimum modulus of elasticity in bending of 1.5 million lb/in^2; rejects ejected for use as fence rails or remanufacture into tree props.
- Survivors of foregoing screening smooth-trimmed on each end to square ends and to remove snipe preparatory to finger jointing, and defect-trimmed to eliminate machining and anatomical defects judged detrimental to ultimate strength in tension and compression.
- Finger-jointed, glued, joined, and radio-frequency-cured in a more-or-less continuous process, with lengths severed at 64 feet (plus 4 inches on either end as trim allowance for damage done during tension proof testing).
- Adhesive in joints more completely cured during transport to tension proof tester.
- 64-foot lengths tension proof tested; rejects recycled through the finger jointers or remanufactured into tree props.
- Machined to shape, and dado-slotted to receive flange web.
- Assembled in pairs with web glued in place, and glue cured.
- 64-foot-long joists precision end-trimmed to length.
- A small proportion of the joists proof tested in edgewise bending.
- Joists strapped in packages, wrapped for shipment, and loaded on flatcars or trucks.

Screening Dowels for Moisture Content and Modulus of Elasticity—With only 3,000 16-foot 8-inch flange dowels to be screened per shift, it seems practical to manually load them transversely directly from kiln pallets onto a lugged chain conveying the dowels past a single-saw end trimmer and passing under three noncontact moisture sensors at quarter points of dowel length. Dowels exceeding 12 percent moisture content at any of the three sensing points will be dye-marked for rejection from the chain and redrying (fig. 5-8). The lugged chain will offload all dowels transversely into a single-point deflection device that applies a 10-pound preload at the centerpoint of a 15-foot span and then senses additional deflection under an additional 20-pound load and marks only those that exceed deflections corresponding to 1,500,000 lb/in^2 modulus of elasticity. On relaxation of the proof load, all dowels will be ejected transversely onto a short grading chain. From the grading chain, an operator will pull dowels requiring redrying, and position acceptable dowels so that a single-saw trimmer will trim snipes from the grader's end. Those failing to meet the stiffness requirement, and those requiring trimming to remove machining defects or anatomical irregularities that would significantly diminish strength of the dowels in tension or compression, will be positioned by the grader for ejection to a reject pallet or to a defect-removal station and return to the chain (fig. 5-8).

In positioning the dowels for end trimming, the offloader and grader will ensure that finger joints will be made in clear wood; that is, knot clusters on dowel ends will be removed by trimming.

Finger Jointing Dowels—As noted above, about 3,000 dowels enter the screening process per shift. Some are withdrawn because they need additional drying, but these will be reintroduced periodically, so these withdrawals do not diminish the piece count going to the finger jointers. About 15 percent (510 dowels per shift) will, however, be withdrawn from the flange plant because they have insufficient modulus of elasticity; these dowels will be sold as fence rails or remanufactured into tree props. Of the remaining 2,550 dowels, about 20 percent will be crosscut into two pieces during defect removal, and reintroduced into the line. The net result of this screening and defect-cutting operation is an increase in per-shift piece count to about 3,060 dowels, about 2,040 of which are 16 feet 8 inches in length, with the balance comprised of random shorter lengths. Allocated over an effective shift length of 400 minutes, this calls for processing nearly eight dowels (that is, shaping 16 ends) per minute through the finger jointers—and curing eight finger joints per minute.

This production is too small for a fully mechanized pair of back-to-back conveyor-fed finger-joint machines which typically cut end joints and apply glue on both ends of 30 to 60 pieces per minute. Instead, a four-operator setup is proposed wherein each operator does the complete job.

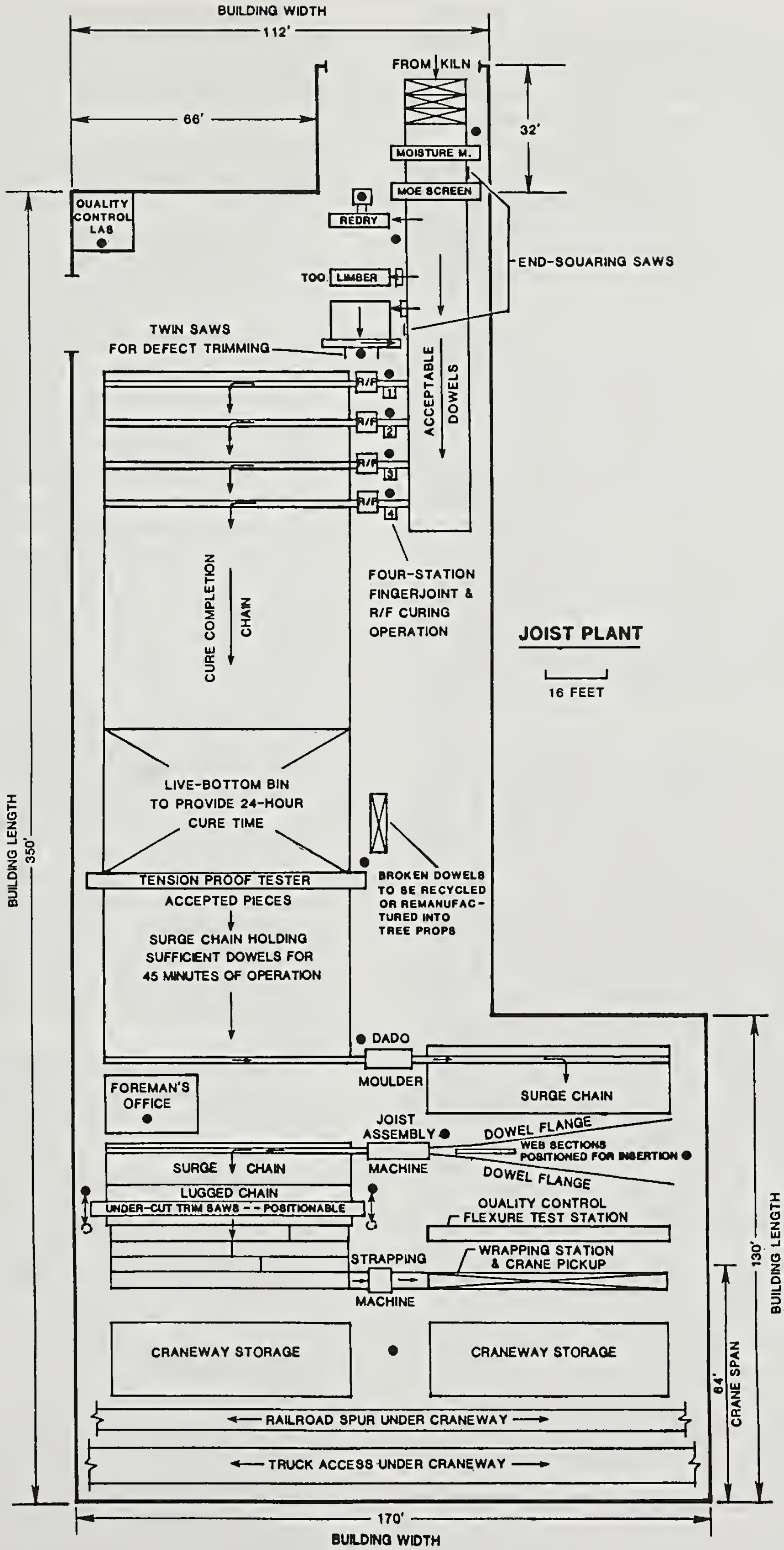

Figure 5-8—Layout of arrangement for screening kiln-dry dowels for moisture content and modulus of elasticity, and subsequent processing into joists of prescribed lengths for shipment by rail and truck.

This entails finger-jointing of both ends of dowel ends; applying to the joints glue, joining the dowels, applying pressure to the joint for curing the adhesive in a radio frequency (RF) unit, advancing the assembly (usually 64 feet plus trim allowance), crosscuttingthe assembly at desired length, and ejecting it onto the cure-completion chain (fig. 5-8). Equipment provided for this cycle must be capable of producing two assembled joints per minute at each of the four operator stations. Since each 64-foot length (usually containing four joints) will be proof tested in tension, this arrangement permits operator accountability for joint quality.

After a minimum of 30 minutes on the transversely moving cure-completion chain, the 64-foot lengths will be transversely deposited in a live-bottom surge bin providing 24 hours of storage before proof testing in tension (fig. 5-8).

Tension Proof Testing of Dowels—Following curing of finger joints in the flange dowels, each will be transversely and singly loaded from curing bin into a tension proof tester, gripped on each end, and subjected to a tension load calculated to stress the dowel flange to about 1.6 times the stress that it will incur when the joist in which it is incorporated is subjected to the joist design load. This load will be held for a minimum of 5 seconds before release and transverse discharge of the dowel to a waiting pallet for storage until introduction to the joist assembly operation.

Flange dowels failing the tension proof test will be sorted into a separate pallet for recycling through the finger-jointing stations or remanufacture into tree props. The tension proof tester will be capable of screening two flange dowels per minute. Per-shift output of acceptable 64-foot lengths will average about 638 pieces.

Dadoing and Machining Dowels—The component dowels comprising each 64-foot length will all have some sweep—averaging about 0.75 inch and not exceeding 1.5 inches. This sweep will be distributed in a variety of planes over the whole 64-foot length. Any single dowel segment can be straightened by application of a 50- to 100-pound force appropriately directed. Before a 64-foot length can be accurately dadoed, clamping or guiding action must be applied to preclude rotation and the length in the region of the dado head must be straightened in all planes and held securely while the dado head cuts.

Such clamping and machining actions can be accomplished at the production rate required (about 150 lineal ft/min) with a specialized moulder equipped with pressure feed rolls before and after the dado head assembly adequate to straighten the dowel in all planes. The dado head assembly will be comprised of two bottom cutterheads, one making a rectangular partial cut to provide a slot into which a guidance key on the moulder bedplate fits, and a second finishing head. To further resist rotation of the dowel, the bedplate following the finishing dado cutterhead will be fitted with a protruding 3/8-inch-wide key to guide each dowel until it exits the moulder.

The moulder will carry two surfacing heads in addition to the two bottom-cutting dado heads. Cutting first—before the first dado head—a bottom jointer will produce a narrow flat on the bottom of the dowels. The final cutterhead on the moulder—a top head—will surface the 1.5-inch-wide flat on the top of each dowel flange (fig. 3-2).

Trials of a standard five- or six-head moulder might prove the adequacy of such standard machines, thus avoiding the extra cost of the specialized moulder just described.

Two to three pallet loads of 64-foot-long flange dowels will enter the moulder per shift, requiring one feeder. Offbearing will be automatic onto a surge chain (fig. 5-8).

Joist Assembly—The flakeboard plant will provide pallet loads of 8-foot-long web sections accurately trimmed to width and with edges prepared for glue adherance and easy insertion into the flange dadoes. Also, the webs will have die-cut circular grooves (knockouts) 1.5 inches in diameter indented at spaced intervals away from the web neutral axis (so that horizontal shear strength of the web will not be adversely affected). The infeed end of the assembly machine will be fitted with keyed guidance members, permitting pairs of dadoed flange dowels to enter on a gentle radius positioned to accurately close on the web sections as they are inserted sequentially into the assembly machine. Just before closure, glue will be applied in the dado groove; and just after closure the web-to-flange glue lines will be radio-frequency (R/F) cured so that edge pressure can be released as the joist exits the assembly machine onto a transfer deck. Alternatively—and perhaps more economically—a vinyl emulsion/isocyanate adhesive could be set in 60 seconds in a continuous press without R/F curing; the economics would depend on the price per pound of R/F curable exterior-grade adhesives (for example, acid-catalyzed phenolic with pH above 2.5, melamine, or phenol-resorcinol-formaldehyde) compared to cost of the isocyanate adhesive.

Output of the assembly machine will average about 42.5 ft/min sustained for the full shift to achieve a scheduled per-shift production of about 638 joists 64 feet in length. Because of operating delays caused by setups, glue replenishing, and infeed positioning of pallets of webs and flanges, the assembly machine will run at about 60 lineal ft/min.

The assembly machine will be fed by two operators. Glue-assembled joists will be discharged from the assembly machine onto a short transfer chain feeding a multiple-saw length trimmer.

Length Trimming of Joists—Most joists destined for rail shipment will be precision trimmed to 64-foot lengths. Joists to be trucked to market will usually be trimmed to shorter specified lengths. The trimmer will therefore be provided with undercut saws that can be positioned to produce the desired length combinations. If necessary, residual end pieces will be salvaged as precision-cut lengths of blocking.

Strapping, Storage, and Shipping—Packages of cut-to-length joists will be strapped for shipment, wrapped (weatherproofed) in pallet loads measuring about 4 feet square, and crane-lifted into temporary storage pending loading onto flatcars or flatbed trucks for transport to distribution centers. As noted previously, per-shift output of the joist plant will be about 319 64-foot-long joists (about four pallet loads), or the equivalent in shorter lengths.

Proof Testing of Joists—At intervals appropriate for the statistical precision required, sample specimens will be drawn from the piles of length-trimmed joists and proof tested in edgewise flexure to ensure integrity of published design strength values.

Connected Horsepower—Connected (electrical motors) in the joist plant power is estimated as follows:

Item	Horsepower
Conveyors incorporating moisture content and MOE determination, grading, and trimming	60
Four finger jointers and associated curing chains and conveyors	160
Four R/F curing units	20
Tension proof tester and associated conveyor	10
Dado moulder and associated conveyor	150
Joist assembly machine and associated conveyors	15
R/F curing unit for joist assembly machine	40
Double-end trim saws and conveyors	15
Strapping machine and conveyors	5
Crane	20
Fans for blowpipes	25
Hog for trim ends	20
Total	540

Staffing—Per-shift staffing of the joist plant will be as follows (not including quality controllers, filers, or maintenance crews; the kiln lead operator is tabulated under the edge-glued panel plant):

Function	Number
Lead operator of joist plant	1
Forklift operator	1
Feeder, grader, and trimmer operator for dowel-screening chain	3
Finger jointers	4
Tension proof tester	1
Moulder feeder	1
Feeders of joist assembly machine	2
Feeders and offbearers of precision joist trimmer	2
Shipper and crane operator	1
Floater	1
Total	17

5-7 PLANT FOR EDGE-GLUED PANELS

As outlined in chapter 3, contemplated annual production of edge-glued panels (figs. 3-5 and 3-8) made from 100-inch-long lodgepole pine bolts will total 11,661 tons (ovendry basis). If panels average 1.5 inches in thickness, annual production will be about 6,500,000 ft^2. Input of stemwood sections for this output is estimated at 37,002 tons annually, ovendry.

About 11.4 percent of this input tonnage will be processed through the short-wood dowel machine (fig. 5-7). Dowels so produced will generally have diameters in the range from 4 to 4.5 inches.

The output of edge-glued panels is largely determined, however, by throughput capacity of the single 100-inch shaping lathe (fig. 3-9), which is estimated at 1,680 bolts per shift turned to cylinders of prescribed size (fig. 3-4)—generally larger than 4.5 inches in diameter. Because the shaping lathe will operate three shifts per day, 7 days per week, 50 weeks per year, annual throughput will be about 1,764,000 bolts or 24,586 tons output from 32,781 tons input (ovendry-weight basis).

This shaping lathe, which will be set to produce residue in the form of flakes 3 inches long and 0.020 inch thick, will be located in the OSB plant adjacent to the disk flaker.

As noted earlier, sound red-knotted 100-inch-long lodgepole pine bolts of appropriate diameter for the edge-glued panels will be diverted into holding bins at the merchandiser. The smaller bolts so diverted will go directly to the short-wood dowel machine, and resulting dowels will be forklifted to a short infeed deck feeding the resaw in the panel plant.

Larger bolts will be forklifted into a hot-water conditioning tank dedicated to feeding the shaping lathe. The layout (see fig. 5-11, p. 66) is such that the occasional misallocated black-knotted bolt can be diverted, as it exits the hot-water tank, to the disk flaker. It is anticipated that about 40 percent of all of the 100-inch bolts of live lodgepole pine in the desired diameter range will be suitable for edge-glued panels.

The shaping lathe is capable of accepting bolts within a range of diameters and making a set for each bolt to achieve maximum prescribed cylinder diameter—in random order. As the machined green cylinders exit the shaping lathe, they will be automatically sorted into live-bottom bins according to diameter (figs. 3-4 and 5-11). These bins will discharge directly into the plant for manufacture of edge-glued panels (figs. 3-5 and 5-2).

Although residence time in these diameter-sort bins must be sufficiently short to preclude development of drying checks, each bin (really a storage deck) must have a holding capacity for a 4-hour run on the bandsaw that follows (fig. 5-9). Holding capacity of each diameter-sort bin will therefore total about 3,600 machined cylinders; thus the bins will measure about 4 feet deep and 150 feet long.

On delivery of the turned cylinders to the plant for edge-glued panels, the following sequence of operations will be performed (fig. 5-9):

- Center splitting the cylinders on a band resaw (in some cases removing a pith-centered stud).
- Kiln drying the half cylinders (and some studs yielded from center cuts).
- Face jointing and oversize blanking the kiln-dry half cylinders; planing the studs on all four sides and double-end trimming them.
- Moulding the blanked half cylinders to trapezoidal shape (fig. 5-10).
- Edge-gluing the trapezoids into panels, sanding the panels, ripping them and double-end trimming them to market size, and packaging them for shipment.

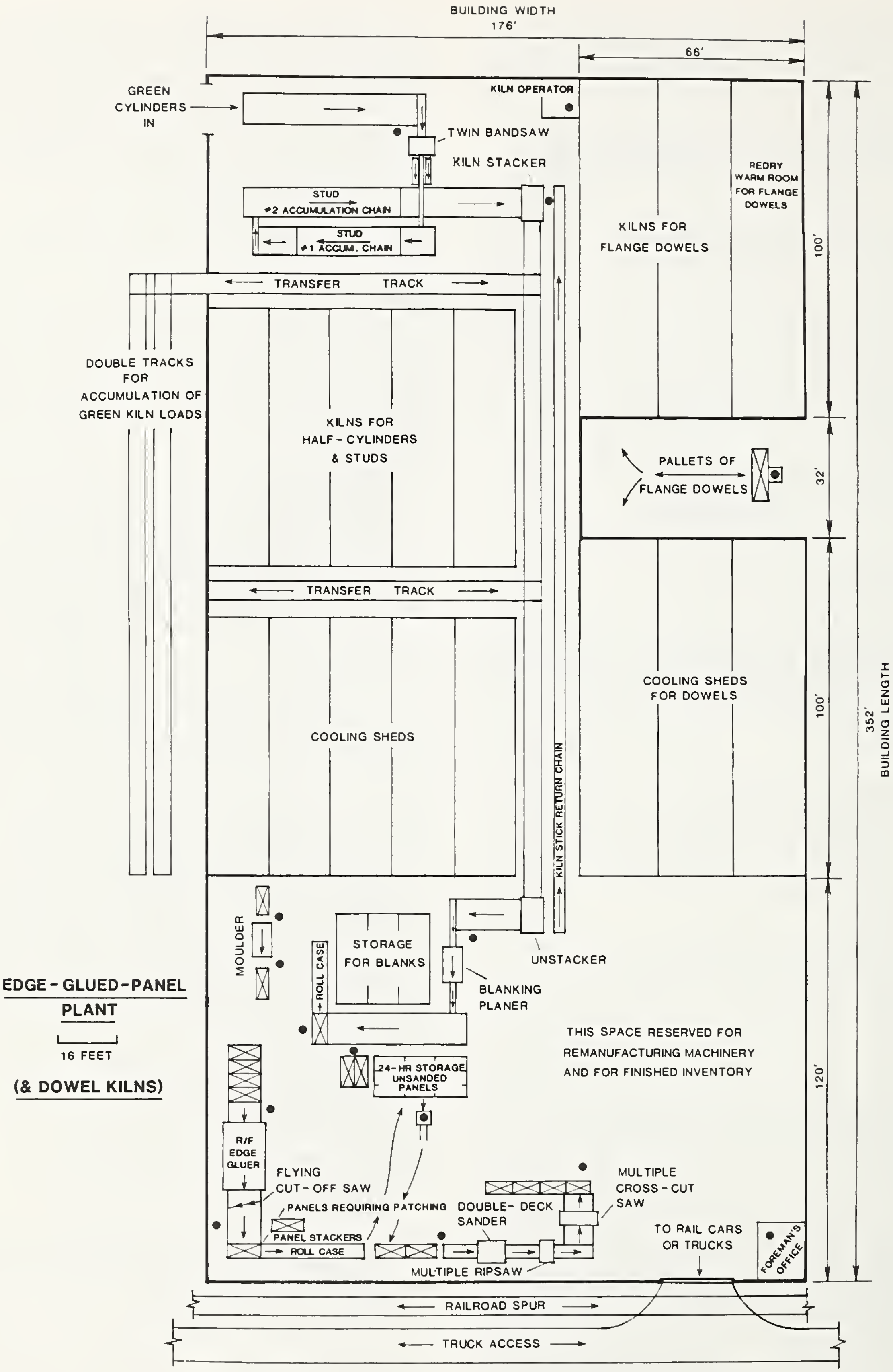

Figure 5-9—Layout of plant for manufacture of edge-glued panels, and arrangement of kilns and cooling sheds for flange dowels.

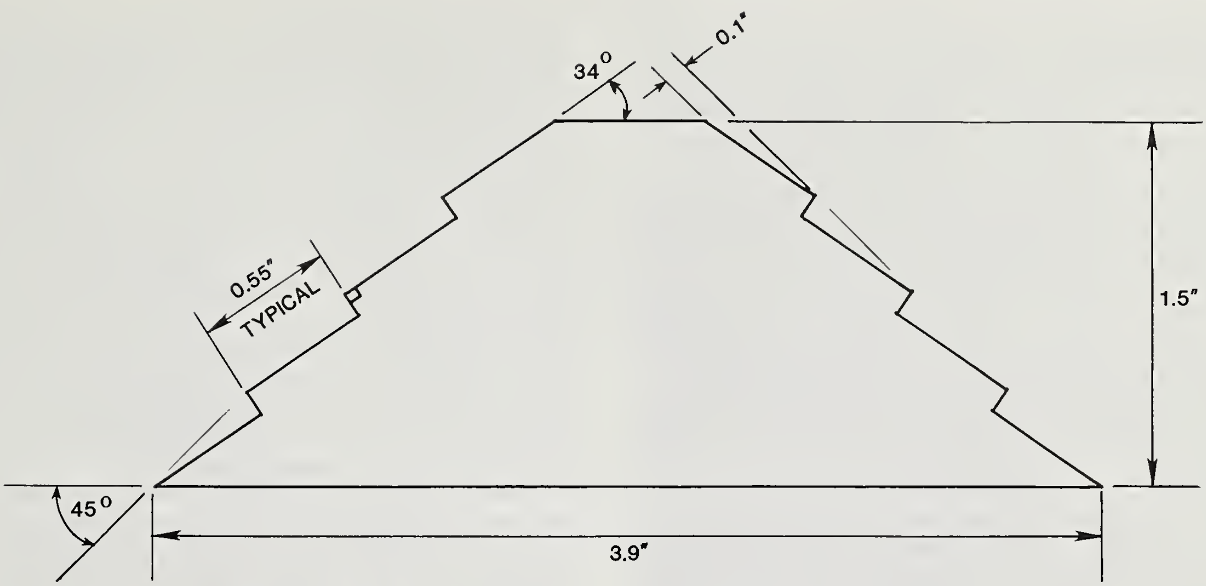

Figure 5-10—One design of edge profile for components of 1.5-inch-thick panels; these components will be cut from half cylinders with diameters (after kiln drying and crook removal) of 4 inches. Profiles for components of panels of other thicknesses will be similar, but not identical. Alternative toothed patterns are possible.

Bandsawing Cylinders

Single-shift, 5-day-per-week operation of the bandsaw is planned. Because annual throughput will be about 1,960,350 100-inch bolts (1,680,000 from the shaping lathe and 280,350 from the short-wood dowel machine), the bandsaw splitter must average 17 bolts per minute (142 lineal ft/min) sustained for each full 480-minute shift. To achieve this average feed speed, the bandsaw must run at about 175 ft/min. About two-thirds of the cylinders will simply require center ripping (fig. 3-4). The remaining third will yield a pith-center stud, and therefore a twin saw will be required. As noted previously, the cylinders will have been sorted by diameter before introduction to the bandsaw, so feed speed can be adjusted for each particular sawing job. The half cylinders will exit onto a transfer chain feeding an automatic stacker. One feeder will be required, and one offbearer who will operate the automatic stacker equipped for insertion of kiln sticks into packages measuring 6 feet wide by 12 feet high. Kiln packages will be handled on kiln trucks and transfer cars.

Pith-centered studs produced will be ejected onto a second accumulation chain with capacity to hold about 1,000 pieces. During interruptions of bandsaw operations (for saw change or setup), these studs will be conveyed onto the end of the transfer chain leading to the automatic stacker (a 6-by 12-foot kiln stack of studs will hold about 935 pieces).

Kiln Drying Half Cylinders and Studs

Kiln holding capacity is based on the time estimated to dry each charge to about 8 percent moisture content. Research data specific to half cylinders are not available, but data on drying 2 by 4 lodgepole pine lumber (Kimball and Lowery 1967; McMillen 1976; Salamon and McIntyre 1971; Troxell 1976) suggest that a 5-day schedule at temperatures not exceeding 190 °F should be sufficient. Temperatures above the boiling point of water should probably be avoided because such high temperatures tend to alter wood color from white to yellowish.

Annual production of half cylinders will total about 3,920,700 pieces, or about 5,446 kiln packages measuring 6 feet wide, 12 feet high, and 100 inches long. Annual production of 2 by 4 studs will total about 750,000 pieces, or about 853 kiln packages with dimensions just described. The foregoing figures are based on using kiln sticks 0.75 inch thick.

The kilns should operate 7 days per week, 50 weeks per year—that is 350 days annually. With an average kiln dwell time of 5 days (70 charges annually), and with double-track kilns, total kiln chamber length needed will be about 382 feet. An arrangement of five kilns each 77 feet long should suffice. The kilns will be equipped with reheat pipes at midwidth between the two 6-foot-wide packages in each double-track kiln.

Roofed cooling sheds of about the same capacity as the kilns are also required.

Face Jointing and Thickness Blanking

An unstacking machine operated by a feeder, with provision for return of kiln sticks to the kiln stacker, will discharge the dry half cylinders (or studs) across a short transfer chain to a six-head planer and matcher. The primary purpose of this machine, which must feed at about 400 ft/min (48 pieces per minute), is to remove most twist from the ripped faces of the half cylinders, to thickness the

blanks oversize thus exposing their knot structure, to establish a more-or-less straight edge for placement against the guide in subsequent moulding operations, and to machine (oversize) the two beveled faces required (fig. 3-4).

The face-jointing (blanking) machine will discharge onto a short grading chain with space to pull black-knotted wood or excessively warped wood not suitable for edge-glued panels; these rejects will be remanufactured into lumber less demanding in knot structure and straightness. The great preponderance of the face-jointed trapezoidal blanks will flow over the end of the chain into an automatic restacker for forklift transport to a moulder. Rejects should be few because of careful grading of the bolts admitted to the center-splitting resaw. One person will identify and pull the rejects, and another will operate the restacker for acceptable wood.

When planing studs, only four heads in the planer and matcher will be employed to surface the studs to 1.5 by 3.5 inches. The transverse grading chain will be equipped to permit double-end trimming of studs following planing, but before restacking. These trim saws will be lowered out of the way when blanking half cylinders.

Moulding

The edges of the trapezoids machined during moulding (fig. 5-10) must be of glue-joint quality; snipes and machine gouges will be unacceptable. While it would be possible to produce the trapezoids on a single planer and matcher operated at 336 ft/min for one shift per day, the reject rate from such an operation might be unacceptably high. An alternative is three-shift operation (243 days per year) of one manually fed moulder yielding 20 knife cuts per inch at a feed speed of 115 ft/min. A moulder appropriate for the job would have jointable spindles carrying eight-knife cutterheads operating at 3,450 r/min. To machine the trapezoids with minimum degrade, such a five-head moulder would have a bottom surfacing head followed by a top thicknessing head and then a pair of tiltable (45 degrees) sideheads to make the finishing side cuts on the trapezoids (fig. 5-10).

Such a moulder operation requires one feeder and one offbearer per shift, with incoming and outgoing loads handled by forklift (about three loads outgoing per hour).

Edge Gluing

As noted earlier, annual production of edge-glued panels should total about 6,500,000 ft^2 (average panel thickness of 1.5 inches). When produced on a single-shift basis, 243 days per year, this is equivalent to 26,749 ft^2 per shift or 105 4- by 8-foot panels per hour. To achieve this output per shift, the 100-inch-long trapezoids must have average edgewise feed speed through the panel edge-gluing press of 7 ft/min sustained for all 480 minutes of the shift. Operating feed rate of the panel press should therefore be about 9 ft/min.

Because of the edge bevels and multiplicity of rather narrow pieces (approximately four glue lines per foot of panel width), glue line area to be cured is large. To minimize length of the continuous press (fig. 5-9), glue lines will be cured with R/F energy. On emergence from the press, the continuous panel will be ripped "on the fly" to a standard width of 48 inches and automatically stacked—at a rate of three to four forklift packages per hour. A second stacker will be provided to accept panels that need patching or remanufacturing to eliminate defects.

An alternative possibility is a batch press for which preloads are assembled in about 48-inch widths and edge ripped to yield a square edge for application of edge pressure. This alternative arrangement would provide more positive edge pressure than the continuous press, but would entail greater wastage in edge trim. Additionally, a batch press might be designed to accommodate stock long enough to make 9-foot garage door rails—a product of high value. Dowels for such longer stock would come from the short-wood dowel machine.

In either case, the acceptable 48-inch-wide, 100-inch-long panels will proceed, after moisture equilibration in stacks, through a wide-belt double sander, and then through smooth-cutting ripsaws and crosscut saws to machine the panels to market size for shipment.

Although machine location is not detailed in the layout (fig. 5-9), space is provided for later addition of remanufacturing equipment such as a moulder, a router, a double-end tenoner, a shaper, and a lathe—all of which may be required to fully exploit the market potential of the edge-glued panel product.

Connected Horsepower

Total connected horsepower for the edge-glued panel plant and for all the kilns should be about as follows:

Item	Horsepower
Kilns including transfer cars, but not stackers or unstackers	1,300
Twin bandsaw with associated infeed and outfeed conveyors	190
Stacker	30
Unstacker	30
Blanking planer and matcher with associated conveyors	220
Moulder	80
R/F edge gluer panel press and associated conveyors and stacker	100
Double-deck sander and associated conveyors	100
Multiple ripsaw, multiple crosscut saw, and associated stacker	100
Fans for blowpipes	75
Total	2,225

Staffing

Staffing for the edge-glued panel plant should be about as follows (all operating a single shift, 243 days per year; except for the moulder feeder and offbearer who are scheduled for three shifts, 243 days per year):

Function	Number of persons
Plant lead operator	1
Kiln lead operator	1
Forklift operator	1
Bandsaw feeder	1
Kiln stacker	1
Kiln unstacker feeding blanking machine	1
Offbearers behind blanker	2
Moulder feeder (three shifts, 243 days)	3 (that is 1 x 3)
Moulder offbearer (three shifts, 243 days)	3 (that is 1 x 3)
Feeder of R/F panel edge gluer	1
Stacker operator behind panel gluer	1
Feeder of double-decker panel sander and trim line	1
Offbearer from trim line	1
Total persons on payroll (exclusive of quality controllers, drivers of log forklifts, and of centralized filing and maintenance personnel)	18

5-8 FLAKEBOARD PLANT

As noted earlier (fig. 3-8), the flakeboard plant will annually produce about 83,535 tons, ovendry basis, of OSB sheathing; this is equivalent to about 137.083 million ft² of panel, 3/8-inch thickness basis. It will also produce 9,365 tons of flakeboard for joist webs, equivalent to 14.271 million ft² (3/8-inch basis). Web flakeboard will be significantly more dense than the OSB sheathing.

Soak Tanks and Flake Production

Soak Tanks—Warm-water heating of wood before it is flaked reduces cutting power required, improves flake quality, and softens knots. Such heating is advantageous the year around, and is particularly needed during the winter months when the wood may be frozen. A wood temperature of about 110 °F is appropriate for lodgepole pine and associated species. Heating time varies with ambient wood temperature, class of wood, and manner of flaking, approximately as follows (water temperature of 150 °F):

Class of wood	Summer	Winter
	- - - Hours	*- - -*
Live lodgepole pine	5	9
Douglas-fir and larch (larger in diameter than the lodgepole)	8	15

Because the live lodgepole pine to be flaked by the shaping lathe (figs. 3-4, 3-9, and 5-11) needs to be heated to a depth of a little more than an inch (just sufficient for roundup into cylindrical shape), it needs less heating time than that going to the disk flakers—perhaps 4 hours in summer and 7 hours in winter.

The dead (bark beetle-killed) lodgepole pine requires more soaking time because it may be very low in moisture content. The first portion of the tanks will therefore be filled with hot water (150 °F) and the second portion with cool water, which will hasten penetration of the absorbed hot water into the center of bolts (for the same reason that a hot preservative dip followed by a cold dip promotes preservative penetration). Research data available are insufficient to accurately predict the soak time required, but it will be significantly longer than for live wood.

The data in table 5-1 and subsequent discussion suggest that holding capacity of the hot-water tanks (fig. 5-11) should be about 2,000 bolts for live lodgepole pine going to the disk flaker, 1,500 bolts for live lodgepole going to the shaping lathe, and about 2,500 bolts for the non-lodgepole pine wood. A tank 5 feet deep and 120 feet long should be adequate for winter heating of the live lodgepole bolts going to the disk flaker. The tank could be as short as 65 feet for the live lodgepole going to the shaping lathe; because of the need to minimize dry-deck storage time of these bolts, however, the hot-water tank will be 120 feet in length—thus providing needed surge storage without risk of check development. The non-lodgepole wood will require a tank about 166 feet long. It is estimated that the beetle-killed lodgepole pine will require a hot tank about 200 feet long followed by a cold tank about 64 feet long. Before the tanks are designed, validation of these heating times and tank dimensions will be required.

To feed the tanks at the rate at which bolts are withdrawn, the yard forklift must maintain an infeed rate of about 800 bolts per hour, 24 hours per day (table 5-1).

Table 5-1—Distribution of classes of 100-inch-long wood entering the flakers

Flaker and class of wood	Ovendry annual tonnage	Ovendry tons/shift[1]	Midpoint average bolt diameter	Bolt weight	Bolts/shift	Bolts/minute[2]
	Tons	*Tons*	*Inches*	*Pounds*		
Disk flaker						
Dead lodgepole	22,000	22.00	5.00	30.49	1,443	3.01
Live lodgepole	41,281	41.28	6.00	43.90	1,881	3.92
Non-lodgepole	45,000	45.00	7.25	64.10	1,404	2.93
Shaping lathe						
Red-knotted lodgepole	32,781	32.78	5.66	39.02	1,680	3.50
Total	141,062	141.06			6,408	13.36

[1]Based on three shifts per day, 350 days per year, less one shift per week devoted to maintenance.
[2]Based on a 480-minute shift.

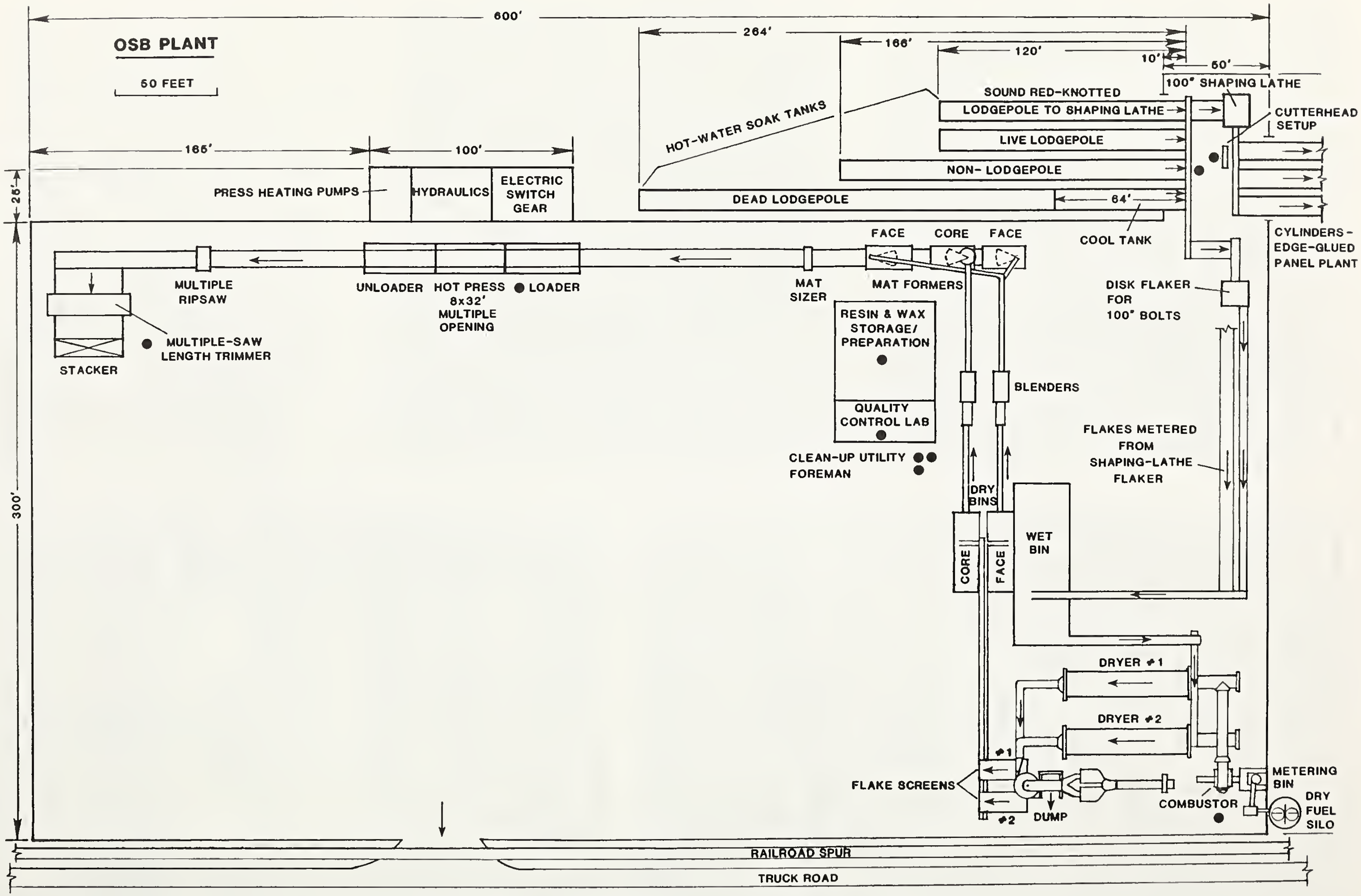

Figure 5-11—Layout of flakeboard plant, showing hot-water soak tanks (leading to the flakers) at the infeed end of the plant. The plant, principally designed to manufacture OSB panels, will also produce flakeboard with random orientation of flakes for pole-joist webs, and could produce oriented-strand lumber.

Flake Production—The infeed end of the plant (fig. 5-11) will be serviced by two flaking machines—a shaping-lathe headrig designed to turn 100-inch-long cylinders of prescribed diameter from sound, red-knotted, live lodgepole pine (figs. 3-4 and 3-9) yielding a residue of flakes 3 inches long and about 0.020 inch thick, and a magazine-type, moving-vertical-disk flaker designed to handle 100-inch-long wood. The shaping-lathe will annually produce about 8,195 tons of flakes (near 100 percent of its capacity), while the disk flaker will annually produce about 108,281 tons (about 54 percent of its capacity), for a total of 116,476 tons, ovendry basis. Additionally, the shaping lathe will yield about 24,586 tons of machined cylinders, ovendry basis. Total wood entering the soak tanks will therefore total 141,062 tons annually.

All bolts entering the plant from the merchandiser (figs. 5-2 and 5-3) will be 100 inches long, but they will have been previously sorted into four classes of wood: sound, red-knotted wood intended for the shaping lathe (and conversion to edge-glued panels), live lodgepole pine not of suitable grade or diameter for edge-glued panels but suitable for flakeboard, dead lodgepole pine, and non-lodgepole—principally subalpine fir, Douglas-fir, and larch. It is estimated that three or four bolts of each class will enter the flakeboard plant per minute, 24 hours per day for 350 days per year (table 5-1). With one shift reserved for maintenance per week, and with 400 minutes per shift of actual flaker operation, about 4.2 bolts per operating minute must be processed on the shaping lathe, and about 11.8 bolts per minute on the disk flaker.

In the layout of the shaping-lathe flaker, particular attention must be given to providing a surge bin from which shaping-lathe flakes can be evenly metered to mix with the disk-cut flakes. This surge bin is required because the shaping lathe produces concentrated flows (lasting about 6 seconds) of flakes about four times per minute. The long-log disk flaker will also produce flakes in intermittent flows (lasting about 13 seconds) timed at about three flows per minute. The wet flakes will be discharged into a live-bottom wet-flake storage bin (fig. 5-11) prior to being metered by picker rolls into a conveyor to the dryers. A flake breaker (to reduce flake width) may be interposed between wet bin and dryers.

One person should be able to feed both flaking machines and at the same time maintain a more-or-less uniform and balanced mixture (table 5-1) of classes of wood entering the disk flaker. Another person will be required full time on each shift to maintain the knives in the two machines. Knife grinding will be done in a centralized facility.

Flake Drying and Screening

As noted previously, annual tonnage of flakes produced will total 116,476 tons, ovendry basis. Because all machines in the flakeboard plant will operate 24 hours per day 350 days per year, with only one shift shut down weekly for maintenance, hourly output of the flake dryers must average about 15 tons, ovendry basis.

Flake Drying—If average moisture content of the wet flakes is 100 percent of ovendry weight, then the dryers must evaporate about 28,000 pounds of water per operating hour. With two dryers in service, each must evaporate 14,000 pounds of water per hour, requiring—at 100 percent efficiency—about 16 million Btu per hour per dryer. To avoid excessive air pollution from the dryers, dryer inlet temperatures will generally not exceed 900 °F. Engineers experienced in rotary-drum dryer design suggest that two triple-pass dryers be employed, each 12 feet in diameter and 60 feet long. Each such dryer has a heat capacity of about 40 million Btu per hour. Flakes discharged from the dryers should have a moisture content of about 2 percent of ovendry weight.

As noted above, inlet temperature to the dryers should be about 900 °F. For this reason, most flake dryers are direct-heated with hot exhaust gases from a dry-fuel suspension burner; in such burners the exhaust gases, which have temperatures in excess of 1,200 °F, are mixed with ambient air to achieve the desired (lower) inlet temperature. The suspension burners are typically fueled with dry-flake fine screenings, and with trim from the finished OSB.

In the proposed operation, however, green hog fuel is in excess supply and dry-flake screenings can be sold to regional particleboard plants. For this reason, it is proposed that the primary heat for the flake dryers come from exhaust gases from the hog-fuel-fired thermal energy plant (fig. 5-2), and only peaking heat come from the dry-fuel-fired suspension burner in the OSB plant (fig. 5-11). The thermal energy plant will therefore require special provision for higher than normal exhaust-gas temperature—that is, at least 1,000 °F. (See also discussion in section 5-11.)

One person will be required on each shift to monitor the dry-fuel suspension burner and the flake drying and screening processes.

Screening—Dry flakes, after passing a fire dump, are discharged through an airlock to two rotary-drum screens to separate the flakes into three categories: fines for fuel (or sale), surface layer strands, and core flakes (the overs).

Fines to be sold are diverted to the shavings bin (fig. 5-2); those to be used as fuel are put in silo storage, withdrawn and hammermilled, and then metered to the suspension burner providing heat for the dryers (fig. 5-11).

Dry face flakes and core flakes are conveyed to their respective live-bottom storage bins and metered out by picker rolls.

Blending of Resins and Flakes

Core and face flakes are withdrawn from the dry storage bin under continuous control of conveyor-mounted weight monitors. The continuously weighed core flakes and face flakes are separately blended with appropriate resins and slack wax. For OSB, and for random-arrangement flakeboard for webs, the conventional resin is phenol-formaldehyde (P-F), but under some circumstances (that is, when pressing 1.5-inch-thick oriented-strand lumber) it may be desirable to employ isocyanate resins in the core layer. The resin and wax preparation room is therefore equipped to mix and appropriately meter phenol-formaldehyde resins, catalysts, and isocyanate resins—as well as wax additives.

Mat Forming

Face Layers—For flakeboard to be utilized in webs, flakes in face layers are randomly oriented. For OSB or oriented-strand lumber, face layers (top and bottom) are continuously formed of strands oriented with axes parallel to the long dimension (32 feet) of the products—that is, parallel to the direction of travel of the forming belt (fig. 5-12). Bottom surface layers are deposited on this wide belt (nominally 8 feet wide) traveling underneath the forming station. The core layer is then deposited, and the top-surface layer former completes the mat forming operation. Thus there are two face-layer formers and one core-layer former (fig. 5-11). The disk-roll forming heads of the surface-layer mat formers have a separating effect, so that the small-size flakes will be deposited onto the belt and on top of the surface layer. In case the largest flakes are wanted on the outer surfaces of the mat, the disk heads need only be turned 180 degrees to achieve this effect.

Core Layer—In flakeboard for joist webs, flake orientation in the core is random. For OSB panels (fig. 3-6), however, core flakes are oriented across the panel in the 8-foot direction, that is, perpendicular to the direction of belt travel. In oriented-strand lumber, core flakes must be aligned in the same direction as the face flakes. This is accomplished by providing a mechanism to turn the core-aligning mechanism 90 degrees to suit the product to be manufactured.

Mat Sizing—The endless, three-layer mat ribbon is transported continuously on a belt conveyor. The weight of the mat is checked, extraneous metal is eliminated, and the ribbon is crosscut to raw mat length (nominally 32 feet) and trimmed to width (nominally 8 feet).

The mats are accelerated by a belt conveyor to provide a gap between mats, required for loading of the hot press within the press cycle.

For manufacture of oriented-strand lumber, which requires a thick mat, it may be that use of a newly developed tacky phenol-formaldehyde resin will permit use of a prepress to reduce mat thickness prior to press loading. Additional research is needed on this aspect of the plant layout.

Pressing

As noted in section 3-2, the flakeboard plant will be equipped with an eight-opening hot press having platens sized to produce trimmed flakeboard panels or oriented-strand lumber 8 feet wide and 32 feet long. An elevator-type mat loader will precede the press, and a panel unloader will follow the press. Thus the length of press with mat loader and panel unloader will be about 105 feet (fig. 5-11).

The platen-type caulless hot press will convert the formed mat of flakes into a bonded panel of desired thickness by densifying it to develop adequate contact between flakes, and by heating it to glue-line temperatures at which the binder cures rapidly.

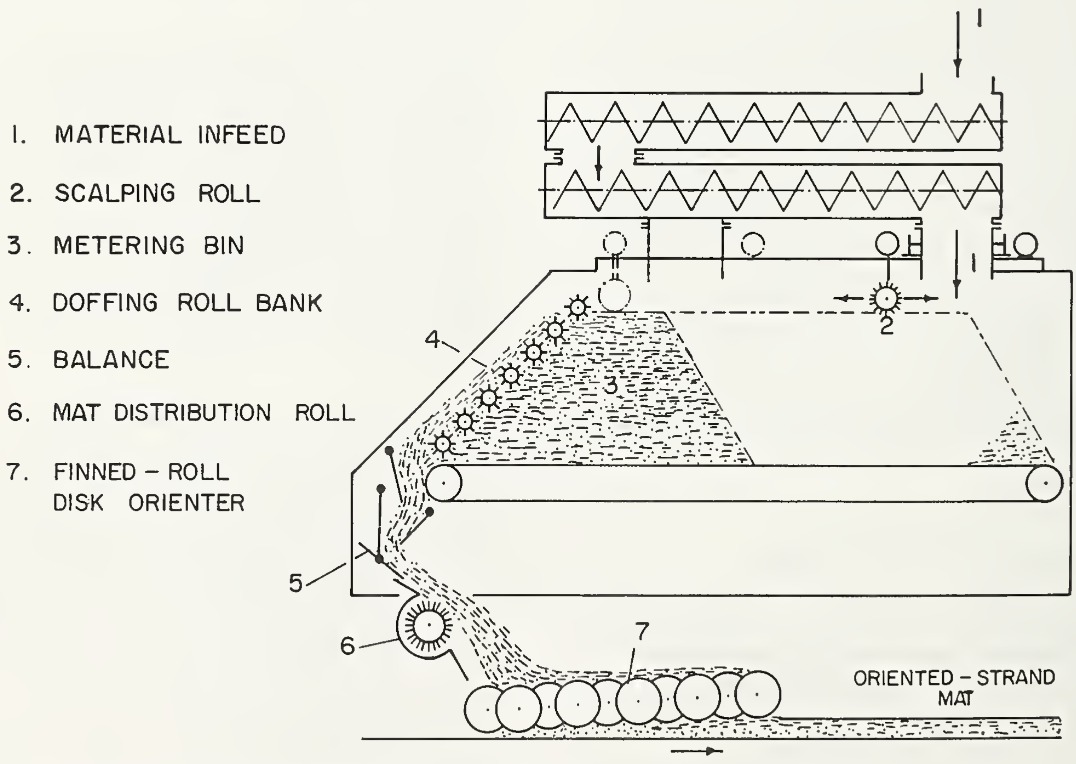

Figure 5-12—Oriented-strand board mat formation. Side elevation of forming head and finned rolls that orient the strands; because most OSB products have three layers, three heads are required to form the complete mat.

Multiple-opening hot presses capable of delivering the high pressures required for flakeboard and oriented-strand lumber are very expensive, and plant capacity is usually determined by press output. This output increases as press cycle time is decreased. For $^{7}/_{16}$-inch-thick OSB sheathing panels bonded with liquid phenol-formaldehyde resin, complete press cycle time will be about $5^{1}/_{2}$ minutes; for $^{3}/_{8}$-inch flakeboard for webs it will be slightly shorter. For 1.5-inch-thick oriented-strand lumber the cycle time will be much longer—as much as 11 or 12 minutes depending on the resin used and the mat moisture content. Research is scheduled to quantify essential parameters controlling manufacture of oriented-strand lumber.

Closing a press to desired thickness in 30 to 60 seconds requires specific platen pressures in the range from 600 to 750 lb/in². An eight-opening press with platens measuring 8 by 32 feet requires 600 to 800 hp to drive hydraulic pumps and pistons adequate to achieve such closing rates.

Platen temperatures are generally in the range from 340 °F (liquid P-F resin) to 420 °F (powdered P-F resin). While it is possible to heat platens to this temperature with high-pressure steam, most plants use presses with oil-heated platens, the oil being heated with energy from combustion of wood residues. (See discussion in section 5-11.)

Blending, forming, and hot pressing are interconnected, highly automated processes, and require only a single operator per shift.

Postpressing Operations

OSB panels to be used as sheathing or floor decking (and random flakeboard for webs) are brushed to remove loose flakes as they emerge from the hot press, scanned by an ultrasonic device to detect interior delamination, and then trimmed on panel-sizing machines resembling two double-end tenoners coupled at 90 degrees to each other so that the large panels (8 by 32 feet) can be reduced to smaller size. Because specialty panels in large sizes command better prices than standard 4- by 8-foot panels, markets for large panels will be sought.

Panels of oriented-strand lumber will be ripped to conventional lumber widths before crosscutting to market lengths.

Since none of the products will exceed 32 feet in length, warehousing and shipping will be accomplished by forklift.

On each shift one person is required to operate the panel-sizing machinery and another to operate the forklift. A third person will likely be needed to perform additional postpressing operations, such as machining tongues and grooves on OSB panels for single-layer floor decking and edge profiles on webs for pole joists.

Connected Horsepower

Connected electrical motors in the flakeboard plant will total about 3,000 hp. Major contributors to this connected total are the shaping-lathe and disk flaker at approximately 500 and 600 hp, respectively; the two rotary flake dryers at about 400 hp each; flake breakers and hammermills with pneumatic transport totaling about 200 hp; and the oil hydraulic system for the hot press at about 600 hp.

Staffing

Staffing requirements in the flakeboard plant (exclusive of quality control and centralized maintenance, saw filing, and knife sharpening) should be about as follows:

Function	People per shift	Number of shifts	Total
Lead operator	1	4	4
Flaking	2	4	8
Flake drying	1	4	4
Hot pressing	1	4	4
Panel sizing	1	4	4
Other postpressing operations	1	4	4
Warehousing and shipping (forklift operator)	1	4	4
Cleanup/utility	2	4	8
Total	10		40

5-9 CENTRALIZED MAINTENANCE, SAW FILING, AND KNIFE SHARPENING

Maintenance facilities (electrical, mechanical, and carpenter) for the plant will be centralized in a shop adjacent to the steam plant (fig. 5-2). Staffing is estimated at five people per shift, 24 hours per day, 350 days per year; as four shifts are required for such continuous operation, the maintenance staff will total 20 people.

Similarly, all saw filing and knife sharpening will be accomplished in a centralized facility employing three people per shift, 24 hours per day, 350 days per year—requiring a total of 12 people engaged in these activivities.

Connected electrical motors in the maintenance shop (two cranes, air compressor, grinders, and machine tools) will total about 30 hp. The various grinding machines in the filing room will total about 25 hp.

5-10 RESIDUE FLOWS

As noted in section 3-3, residues from plant operations will total 106,390 tons annually, ovendry-weight basis. Of these residues, the pulp chips and dry planer shavings will be accumulated in bins (fig. 5-2) and sold to mills in the Missoula area. All or part of the dry flake screenings can also be sold as furnish for particleboard, depending on the fuel needs of the plant. Green hog fuel (mostly branchwood and waste from doweling operations) and stembark will be consumed in the central steam plant. Annual production of these residues should be about as follows (fig. 3-8):

Residue description	Annual production	
	Tons, ovendry basis	
Salable		
Pulp chips	6,508	
Dry shavings	14,379	
		20,887
Sometimes salable (depending on fuel needs)		
Dry flake screenings and trim		23,576
Fuel for plant consumption		
Bark	20,000	
Green hog fuel	41,927	
		61,927
Total		106,390

5-11 THERMAL ENERGY PLANT

The preponderence of fuel for the thermal energy plant originates at the delimber-debarkers (branches and bark), the dowel plant (residue from the dowel machines), and from the flakeboard plant (dry flake screenings and panel trim). The energy plant is therefore located in proximity to these sources (fig. 5-2). Adjacent space for periodic accumulation of excess fuel is indicated on the site plan.

Connected electrical motors in the furnace system will total about 325 hp and will run at about 75 percent of capacity. System circulating pumps will total about 365 hp, including standby pumps. The overall connected total will be about 690 hp.

The thermal energy plant will have one supervisor working a single shift and responsible for overall operation. Two operators will staff the plant on each of four shifts required for 24-hour operation 350 days per year.

Fuel Tonnage Required for Process Heat

All needed electrical energy will be purchased from outside sources. Heat energy required by the plant will be substantial, however, and—as noted above—this heat energy will be supplied from a thermal energy plant fueled primarily by green hog fuel and bark. Primary components of the heat requirement include energy for heating of work spaces, heating hot ponds to condition bolts entering the flakeboard plant, drying flakes, heating the OSB hot press, kiln drying half rounds to be assembled into edge-glued panels, and kiln drying flanges for fabricated joists.

Working space to be heated is about as follows:

Building	Area
	Ft²
Administrative office	4,000
Weight-scale office	500
Shelters for delimber-debarkers	8,000
Dowel plant	15,360
Joist plant	48,150
Edge-glued panel plant (excluding kilns)	28,600
Flakeboard plant	186,000
Thermal energy plant, central maintenance shop, and central filing and sharpening room	7,200
Total	297,810

Only a few of these spaces will be heated above 50 °F; total wood requirement should not exceed 600 tons annually, ovendry-weight basis.

Energy required to hold the hot-water soak tanks at 150 °F year around can only be roughly estimated. About 141,062 tons of wood (ovendry) will enter the hot-water vats annually. This wood will contain about an equal weight of water. At 100 percent efficiency, 15,600 million Btu are required to raise this tonnage of water from an average bolt temperature of about 45 °F to about 100 °F. As the specific heat of wood is about one-third that of water, about 5,200 Btu are required to heat the wood, for a total of 20,800 million Btu annually at 100 percent efficiency. With heat losses in the vats estimated at 50 percent, and boiler efficiency at 60 percent, total Btu requirement annually should be about 20,800 million ÷ (0.5 x 0.6) = 69,333 million Btu. At 8,600 Btu content per pound of ovendry wood, this is the equivalent of the heat content of about 4,031 tons of wood annually, ovendry-weight basis.

Industrial experience has shown that direct-fired flake dryers require as much as 20 percent of the flakes (that is, screenings plus trim) to dry the remaining 80 percent of the flakes. Therefore, about 23,295 tons of fuel will be required to dry the 116,476 tons of flakes produced annually (ovendry-weight basis).

Industrial experience has also shown that bark from stems that are flaked provides sufficient heat energy to heat the hot press that forms panels from flakes. Because bark comprises about 10 percent of stem weight, this suggests that the fuel requirement to heat the flakeboard hot press should total about 11,648 tons annually, ovendry-weight basis.

About 27,541 tons of half logs will be kiln dryed annually for conversion to edge-glued panels; additionally about 23,779 tons of flange dowels will be dryed annually, for a total of 51,320 tons annually (ovendry-weight basis). About 46 percent of the energy required to kiln-dry wood is expended in evaporating the water the wood contains. If the water in the wood is equal in weight to the ovendry wood, and about 90 percent of the water is to be removed during kilning, the total annual Btu requirement will be about:

(0.9 x 51,320 x 2,000 x 1,100 Btu per pound of water evaporated) ÷ 0.46 = 220,899 million Btu annually

Because hog-fuel energy cells are only about 60 percent efficient (possibly 70 percent), fuel required annually for kiln drying must contain about 368,165 million Btu. At 8,600 Btu per pound, the annual fuel requirement for kiln drying should be about 21,405 tons (ovendry-weight basis).

The foregoing hog fuel requirements are summarized as follows:

Purpose	Annual fuel requirement
	Tons, ovendry-weight basis
Heating of working spaces	600
Heating water for flakeboard conditioning vats	4,031
Drying flakes for flakeboard	23,295
Heating flakeboard hot press	11,648
Heating dry kilns	21,405
Total	60,979

This summary suggests that, with sale of pulp chips and shavings only, there will be a significant excess of fuel (85,503 – 60,979 = 24,524 tons, ovendry, annually), creating a substantial disposal problem. Possibilities for reducing this excess include:

- Forest delimbing of the trees harvested from National Forests. At the expense of considerable labor, this would reduce incoming fuel by 20,000 tons, ovendry, annually.
- Sale of dry flake screenings to a particleboard plant; this would reduce fuel by 23,295 tons.
- Development of doweling machines to produce flakes (preferable) or pulp chips as residues when manufacturing the flange dowels; this would reduce fuel by 15,853 tons.

Another alternative would be to increase fuel consumption by addition of steam turbines driving electrical generators to supply needed power for the plant (see section 5-14).

5-12 ADMINISTRATIVE STAFF

Because most of the plant will operate 24 hours per day for 350 days per year—that is, with a four-shift schedule—four plant superintendents will be required (one for each shift). Additionally, the flakeboard plant and the joist plant will each need four shifts of a quality control person, and the edge-glued panel plant will require a quality controller for a single shift. Also, four security guards at the main gate (one per shift) will be required. Security of the truck gate will be monitored from the weight-scaling station, and thus require no additional administrative personnel. Working only the day shift, 5 days a week, will be the following additional administrative and sales staff:

Function	Number of people
General manager	1
Plant manager	1
Sales and sales engineering	6
Accounting and purchasing	1
Plant engineer	1
Personnel manager	1
Secretarial	3
Total	17

As noted in section 2-5, the procurement operation will be organized as a separate corporate subsidiary to the principal corporation. The payroll of this subsidiary corporation will be allocated to wood cost.

5-13 SUMMARY OF STAFFING REQUIREMENTS

Exclusive of procurement operations, total staff required will be about 271 people (table 5-2).

Table 5-2—Staffing required for the entire operation, exclusive of wood procurement

Plant segment or function	Personnel per shift	Number of shifts operated	Total people on payroll
Weight-scaling station	1	2	2
Portal crane	1	4	4
Debarking-merchandising	7	4	28
Doweling plant	7	4	28
Joist plant	17	4	68
Edge-glued panel plant and kilns	18	1	18
Flakeboard plant	10	4	40
Thermal energy plant supervisor	1	1	1
Thermal energy plant	2	4	8
Knife grinders and saw filers	3	4	12
Maintenance	5	4	20
Quality control			
OSB	1	4	4
Joists	1	4	4
Edge-glued panels	1	1	1
Trainees for manufacturing jobs,and to fill in for absentees	2	4	8
Security at main gate	1	4	4
Superintendents	1	4	4
General administration			
Plant engineer	1	1	1
Sales (and sales engineering)	6	1	6
Accounting (and purchasing)	4	1	4
Personnel manager	1	1	1
Secretarial	3	1	3
Plant manager	1	1	1
General manager	1	1	1
Total			271

5-14 SUMMARY OF CONNECTED HORSEPOWER IN PLANT

From the foregoing discussions, plant-connected horsepower can be summarized as follows:

Item	Horsepower
Portal crane	340
Delimbers-debarkers and merchandisers	1,200
Dowel plant	400
Kilns	1,300
Joist plant	540
Plant for edge-glued panels	925
Flakeboard plant	3,000
Thermal energy plant	690
Central maintenance shop	30
Central knife sharpening and filing room	25
Pumps for water supply	100
Total	8,550

Many, if not most, of the electrical motors in the plant will operate with intermittent loads, and most of the loads will vary during each shift. Averaged over the entire operation, the mean power demand will probably be about 60 percent of the connected load; that is, the mean power demand will average about 5,070 hp.

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CHAPTER 6: PLANT AND EQUIPMENT COSTS

CONTENTS

Plant capital costs can be aggregated by summing site acquisition and preparation costs with the costs of the various plant components, as outlined in the following sections and summarized in section 6-16. Supervisory costs of machinery suppliers during plant erection, startup, and training are included as part of capital costs—but not the payroll costs of management and workforce during these periods.

6-1 SITE ACQUISITION AND PREPARATION

A minimum of 55 or 60 acres is required for the plant (fig. 5-2), plus perhaps 10 acres separate from the plant site for disposal of refuse from the bottom of the hot-water soak tanks and for settling ponds used perhaps twice yearly to dispose of water exchanged in the soak tanks.

At this point in the analysis, when a definite site has not yet been identified, costs of site acquisition and preparation can only be approximated. Regardless of location, however, costs can be segregated as follows to permit approximation for budget purposes.

Acquisition

Ideally, a site might be located with rail siding in place—but this seems unlikely. A bare site without a siding but adjacent to the railroad so that a siding could be constructed, with access to electric power and to truck-traversible roads, and with appropriate contour and soil (and water supply) might sell for $2,000 per acre. Site cost might therefore be approximated at $140,000 (including the 10-acre disposal site).

Access Road to Site

Cost of improving (probably not constructing) an access road obviously will vary with site location. In the absence of specific site information, this cost is approximated at $15,000 per mile for 1 mile, for a total of $15,000.

Grading

Because the plant requires level terrain, only essentially level sites can be considered. If 20 days of bulldozer or grader work were required at $150 per hour, the total cost would be about $24,000.

Electrical Service

Cost of extending electrical service to the site, together with purchase of necessary transformers, is estimated at $100,000.

Water Supply

In the proposed plant, water is required for the thermal energy plant (some steam generation), for summer sprinkling of the log deck under the portal crane, for blending with resins to prepare adhesive binders, for replenishing the hot-water soak tanks, for toilets in the various plant components, and for drinking and washing. In most of the locations under consideration, all but potable water should be available from the Kootenai River. A well will be required for potable water.

The thermal energy plant will have a closed-loop water system to the extent practical.

Development of a potable-water well is estimated to cost $10,000. A pumping station to withdraw river water is estimated to cost $25,000. The total is therefore approximated at $35,000. (The budget for the thermal energy plant includes some additional funds for development of the water supply; see also section 6-14 for the sprinkler-system budget.)

Sewage and Waste-Water Disposal

Sewage from the various plant buildings will be disposed of in septic tanks—probably five in all. Construction of these septic tank systems should cost about $14,000. Waste water will come primarily from the resin mixing centers in the OSB plant and the joist plant, and from the hot-water soak tanks. Also, there will be some runoff from summer sprinkling of the log deck.

As noted previously, the water from the hot-water soak tanks (when it must be replaced) will be pumped out and transported to settling ponds at some distance from the plant site; tank sludge will be removed by front-end loaders and also transported to the disposal site. Similarly, the waste water from the resin mixing centers will be contained and transported to the settling ponds. The cost of holding tanks for the waste water from the resin mixing centers, and preparation of the settling ponds is estimated at $15,000.

The total for this segment of cost should therefore be about $29,000.

Storm Drains

Storm drains directing rain water are estimated to cost about $15,000.

Railroad Siding

A minimum of 2,200 feet of rail siding must be constructed, with two crossings of a truck-loading road (fig. 5-2). Installed cost of treated crossties with hardware will be about $34 per tie; if installed with 21¼-inch spacing, about 1,242 ties will be required, yielding an installed cost of about $42,000 plus the cost of rails. Total cost of the siding is approximated at $60,000.

Interior Roads

About 10,000 feet of roads are required within the plant perimeter (fig. 5-2). At a cost of $15,000 per mile these roads will cost about $28,000.

Paving

A few of the high-traffic areas for forklift operation will be paved; $30,000 is allotted for this purpose.

Perimeter Fences, Gates, and Guardhouse

Perimeter chain link fencing (6 feet high with three strands of barbed wire on top) needed will total about 6,400 feet. Two gates will also be needed, each with a remotely controlled barrier bar. At $6 per lineal foot of fence including the cost of the gates, and $2,000 per barrier bar, the total fencing cost should be about $42,000. The guardhouse is estimated to cost $4,000, giving a total for fencing and guardhouse of $46,000.

Summary

Estimated site acquisition and preparation costs are summarized as follows:

Item	Cost
Acquisition	$140,000
Access road to site	15,000
Grading	24,000
Electrical service (transformers owned by plant)	100,000
Water supply	35,000
Sewage and waste-water disposal	29,000
Storm drains	15,000
Railroad siding	60,000
Interior roads	28,000
Paving	30,000
Perimeter fences, gates, and guardhouse	46,000
Total	$522,000

6-2 PORTAL CRANE

Installed cost of the portal crane (figs. 5-1 and 5-2) is comprised of several elements, as follows:

Item	Estimated cost
Site profiling, compaction and drainage	(Covered in previous paragraphs)
Machinery (the portal crane)	$1,360,000
Erection	200,000
Freight	50,000
Rail installation	325,000
Portable sprinkler system for log deck	10,000
Total	$1,945,000

The foregoing costs include supervision by the manufacturer during erection, startup supervision, and training of the crane operators.

6-3 DELIMBERS-DEBARKERS AND MERCHANDISERS

It is difficult to estimate the installed cost of the delimber-debarker and merchandiser layout as diagramed (fig. 5-3) because it is a departure from previously built merchandisers—that is, it calls for handling whole trees of small diameter through delimbers coupled to debarkers, and then segmenting these stems to maximize their value.

A senior consulting engineer experienced in designing tree merchandisers estimates that the complete layout installed (fig. 5-3), with required engineering, building, startup supervision, and spare parts, will cost $6.5 to $7.5 million, of which nearly $3 million is assigned to development and construction of the two merchandisers. For budget purposes, the cost is estimated at $7 million. Additionally, $150,000 will be needed to purchase a forklift designed for rapid handling of log segments from the point of discharge from the merchandiser to the dowel plant, kilns, and flakeboard plant. Thus the total cost is estimated at $7,150,000, including pulp-chip loading facilities and a conveyor to move residue (hogged limbs and bark) to the thermal energy plant.

6-4 DOWEL PLANT

Cost of the dowel plant (fig. 5-7) can be estimated from the sum of its components, as outlined in the following paragraphs.

Building

The dowel plant will have about 15,360 ft² under roof. No overhead cranes or exceptionally high clearances are required. Dowel machines will be installed at more-or-less ground level, with residue conveyors somewhat below ground level. Except for the tree-prop pointer and chamfer machines, no blowpiping is required. During winter, the building will likely be heated to about 50 °F. With the foregoing in mind, it should be possible to construct the building for about $20/ft², or about $307,000.

Machinery Groups

Doweling machines are available locally in Montana (Bouma), or from West Germany (Bezner). With infeed and outfeed conveyors, switch cabinets, cutterheads, tools, and accessories (but not with log decks or grading chains), the machines can be purchased for about $60,000 to $96,000 each depending on manufacturer and machine size. For the five machines needed, the average should be about $78,000, for a total of $390,000.

The tree-prop pointer and top chamfering machine can be constructed for a total of about $10,000, including cutterheads and starting switches.

Structural Steel, Sheet Metal, and Piping

This equipment grouping includes five two-section infeed log decks and a grading chain, all estimated to cost about $55,000 installed.

Inplant conveyors collecting residue from the dowelers will cost about $15,000, and the blowpipe system for the pointing and chamfering machines will cost about $3,000. Additionally, a long residue conveyor is needed to transport residues to the thermal energy plant; this conveyor is estimated to cost $20,000.

All of the foregoing items under this heading total $93,000.

Machine Foundations and Installation

Foundations for machines and conveyors, and their installation on the foundations, are estimated to cost $25,000.

Spare Parts

Spare parts for the dowelers, the tree-prop pointer and chamfering machines, and the conveyors will cost about $25,000.

Electrical Service (Supplemental to Machinery Groups)

From tranformer pole to machine and conveyor switchgear supplied with the machines, dowel plant electrical service costs will be about $5,000.

Engineering

Engineering design costs are estimated at 4½ percent of all of the foregoing, that is, 0.045 x $855,000, or about $38,000.

Supervision (by Machine Manufacturers)

Erection—Supervision by the machine manufacturers should not be necessary during erection of the dowel plant.

Startup—The manufacturer of the dowel machines should provide startup services as part of the purchase price.

Training—Extended training, beyond the startup period, should not be needed in the dowel plant.

Summary of Costs

Total estimated cost of the dowel plant is as follows:

Item	Cost
Building	$307,000
Machinery groups	400,000
Structural steel, sheet metal, and piping	93,000
Machine foundations and installation	25,000
Spare parts	25,000
Electrical service	5,000
Engineering	38,000
Supervision by machine manufacturers	0
Total	$893,000

6-5 KILNS

Dowel Kilns and Kiln Pallets

As noted in section 5-6 and figure 5-9, two dowel kilns each 100 feet long, about 22 feet wide, and with space for loads up to 12 feet high are required for the primary drying job. Additionally, a redry room of the same dimensions is required for those dowels not sufficiently dry to pass moisture-content inspection on entry to the joist plant (fig. 5-8). Erected cost of these three steel-frame aluminum-panel kilns with all heating coils, controls, fans, motors, and spares—and including startup supervision by the manufacturer— is estimated to total $600,000.

Validation of drying schedules is budgeted at $20,000.

As previously noted, a working inventory of dowel pallets should number about 500. At a cost per pallet of $100, the total acquisition cost of the 500 pallets should be about $50,000.

Kilns for Half Cylinders and Studs

As noted in section 5-7 (see also fig. 5-9), five double-track kilns each measuring about 75 feet long, with width and height sufficient to accommodate kiln loads 6 feet wide and 12 feet high, are needed to dry half cylinders and studs. Each of these five kilns will cost about the same as the dowel kilns, that is, $200,000 each for a total erected cost of $1 million including spare parts and startup supervision.

Cooling Sheds

Also needed are eight cooling sheds each equal in length to the corresponding kiln (fig. 5-9), for a total of 14,000 ft^2. At $10/ft^2, total shed price (erected) should be about $140,000.

Summary of Costs

Total estimated cost of the kilns, dowel pallets, and cooling sheds is summarized as follows:

Item	Cost
Dowel kilns	$ 600,000
Validation of drying schedules	20,000
Dowel pallets	50,000
Kilns for half cylinders and studs	1,000,000
Cooling sheds	140,000
Total	$1,810,000

Included in this total are the transfer cars and tracks (fig. 5-9), but not the stacker and unstacker, which are costed as part of the plant for edge-glued panels.

6-6 JOIST PLANT

Building

The joist plant (fig. 5-8) will have about 48,150 ft^2 under roof. Some long spans are required, as is a craneway adjacent to the loading dock. Blowpipes to remove sawdust and shavings from the finger-jointing machines, dado moulder, double-end trim saw, and hog for trim ends will be required. During winter the building will likely be heated to about 55 °F.

With the foregoing in mind, building costs are estimated at $23/ft^2, or about $1,107,000.

Machinery Groups

Primary machine costs are estimated as follows:

Machine	Cost
Conveyor incorporating moisture content and MOE evaluation, and end and defect trim	$100,000
Four-station finger joint and curing operation	400,000
Tension proof tester	20,000
Dado moulder	150,000
Joist assembly machine	150,000
Double-end trim saw machine	10,000
Joist flexure test machine	15,000
Strapping machine	20,000
Crane over storage and shipping area	25,000
Inplant forklift	20,000
Air compressor	5,000
Quality control equipment	10,000
Total	$925,000

Structural Steel, Sheet Metal, and Piping

Conveyor chains and drives not listed under the previous heading, structural steel, sheet metal, and piping, are estimated to cost $70,000.

Machine Foundations and Installation

Machine foundations and installation of the machines and conveyors on their foundations will cost about $50,000.

Spare Parts

At 5 percent of the cost of machinery plus structural steel, sheet metal, and piping, spare parts will cost about $50,000.

Electrical Service

From transformer pole to machines and conveyor switchgear supplied with the machines, joist plant electrical service costs will be about $15,000.

Engineering

Engineering design costs are estimated at 4½ percent of all the foregoing, that is, 0.045 x $2,217,000 or about $100,000.

Additionally, $75,000 is budgeted for intensive engineering assessment and selection of equipment to finger-joint and glue-cure the joist flanges, equipment to machine the joist flanges and webs, and equipment and adhesives to fasten joist flanges to the webs.

The engineering budget for the joist plant therefore totals $175,000.

Supervision (by Machine Manufacturers)

Erection—Supervision by the machine manufacturers during erection should be minimal, perhaps totaling $10,000.

Startup—The manufacturers of the major machines should provide primary startup services as part of the purchase price. Some extended startup services may be needed, however, so $20,000 is budgeted for this purpose.

Training—Some employee training will be needed in moisture content and MOE determination, finger joint cutterhead grinding and setup, tension proof testing, dado moulder setup and maintenance, joist assembly, and joist flexure testing; $30,000 is budgeted for this training.

Summary of Costs

Total estimated cost of the joist plant is estimated as follows:

Item	Cost
Building	$1,107,000
Machinery groups	925,000
Structural steel, sheet metal, and piping	70,000
Machine foundations and installation	50,000
Spare parts	50,000
Electrical service	15,000
Engineering	175,000
Supervision by machine manufacturers (erection, startup, and training)	60,000
Total	$2,452,000

6-7 PLANT FOR EDGE-GLUED PANELS

Building

Excluding the kilns, the plant for edge-glued panels (fig. 5-9) has 28,600 ft² under roof. The area housing the unstacker and panel manufacturing facility will be heated in winter to perhaps 55 °F. At the infeed end of the plant, only the kiln lead operater's office and the operators' stations for the twin bandsaw and the kiln stacker will be heated—likely by radiant heaters. Heat from the kilns will also ameliorate winter temperatures in the bandsaw area.

No overhead cranes or exceptionally high clearances are required. The bandsaw will be elevated somewhat to permit servicing and to provide clearance for a sawdust conveyor leading to a hog-fuel bin. The balance of the equipment will be installed more or less at ground level, with only sufficient elevation to provide convenient working levels at the various sorting chains. A blowpipe system will remove shavings and sawdust from the blanking planer, moulder, panel cutoff saw, and panel rip and crosscut saws and deliver these residues to the adjacent shavings loading station (fig. 5-2). Dust from the panel sander will probably be piped to the fuel bin, as it has little potential as particleboard furnish and therefore should not be discharged to the shavings bin.

With the foregoing in mind, building cost is estimated at $20/ft², or about $572,000.

Machinery Groups

Primary machine costs are estimated as follows:

Machine	Cost
Twin bandsaw with infeed chain and offbearing belts	$ 130,000
Kiln stacker	70,000
Kiln unstacker	70,000
Blanking planer and matcher (used Stetson-Ross 6-10A1 or used Yates A-66 motorized planer and matcher with bottom head cutting first under a yielding holddown)	60,000
Stacker behind blanking planer	15,000
Moulder	75,000
R/F edge gluer with flying cutoff saw	160,000
Panel stacker	10,000
Double-decker panel sander	75,000
Panel multiple ripsaw	120,000
Panel multiple crosscut saw	120,000
Panel stacker	10,000
Conveyors including:	60,000
Infeed and outfeed decks to twin bandsaw	
Infeed deck to stacker	
Stick-return conveyor to stacker	
Infeed and outfeed conveyers for blanking planer	
Outfeed roll case for panel press	
Air compressor	5,000
Inplant forklift	20,000
Total	$1,000,000

Structural Steel, Sheet Metal, and Piping

The blower system to remove dry sawdust and shavings from panel manufacturing operations and the shavings bin (for truck loading) are estimated to cost $60,000. The green-sawdust conveyor from the bandsaw, the sander-dust blowpipe, and the fuel accumulation bin holding these two residues is estimated to cost $20,000.

Structural steel and sheet metal not previously tabulated is estimated to cost about $15,000.

Machine Foundations and Installation

Machine foundations and installation of machines and conveyors on the foundations are estimated to cost $55,000.

Spare Parts

At 5 percent of the cost of machinery groups plus structural steel, sheet metal, and piping, spare parts will cost about $55,000.

Electrical Service

From transformer pole to machines and conveyor switchgear supplied with the machines, electrical service to the plant for edge-glued panels will cost about $15,000.

Engineering

Engineering design costs are estimated at 4½ percent of all the foregoing, that is, 0.045 x $1,792,000, or about $81,000.

Additionally, $30,000 is budgeted for intensive assessment and evaluation of jointing and edge-gluing equipment.

The engineering budget for the edge-glued panel plant therefore totals $111,000.

Supervision (by Machine Manufacturers)

Erection—Supervision by the machine manufacturers during erection should be minimal, perhaps totaling $10,000.

Startup—The sellers of the major machines should provide startup services as part of the purchase price. Some extended startup services may be required, however, so $20,000 is budgeted for this purpose.

Training—Some employee training will be needed in machine setup of the twin bandsaw, blanking planer, moulder, panel press, double-decker sander, and panel cutup machines; $30,000 is budgeted for this training.

Summary of Costs

Total estimated cost of the plant for edge-glued panels is estimated as follows:

Item	**Cost**
Building	$ 572,000
Machinery groups	1,000,000
Structural steel, sheet metal, and piping	95,000
Machine foundations and installation	55,000
Spare parts	55,000
Electrical service	15,000
Engineering	111,000
Supervision by machine manufactures (erection, startup, and training)	60,000
Total	$1,963,000

6-8 ORIENTED-STRAND BOARD PLANT

Estimation of the cost of the plant to make oriented-strand panels and lumber can be approached by summing the cost of components based on current costs of machinery groups. An alternative method, probably equally serviceable, is estimation based on what comparable plants have cost to build within the last few years. For lack of better information, the latter approach is used in this section. Because site acquisition, and log scaling, storage, and debarking are costed in sections 6-1 and 6-2, these costs are not included in the cost of the OSB plant. Also, the thermal energy plant, central maintenance shop, central knife sharpening and filing room, general office, and plant sprinkler system are costed in sections 6-9 through 6-14; these costs are therefore not included in the following estimate of the OSB plant.

Recently, stand-alone OSB plants of about the capacity of the one contemplated here have been built elsewhere in the United States at costs from $20 to $40 million. Considering the major plant elements noted in the previous paragraph that have been costed separately, it seems reasonable to estimate the erected cost of the OSB plant itself (fig. 5-11) at $30 million, including manufacturers' supervision during erection, startup, and training.

6-9 THERMAL ENERGY PLANT

Installed cost of the thermal energy plant, including startup and operator training, is estimated at $3,400,000.

6-10 CENTRAL MAINTENANCE SHOP

The central shop (fig. 5-2) is charged with maintenance of buildings, fixed machinery, and rolling stock within the plant. It therefore must be equipped not only for carpentry, welding, plumbing, and machining, but also for sheet metal, hydraulic, and electrical work.

It is projected to measure 40 by 60 feet (2,400 ft²). Because of its provisions for comfortable working temperatures in winter, overhead cranes, pits for maintenance of forklifts, and cabinetry for storage of tools and supplies, the clear-span structure is estimated to cost about $40/ft² or $96,000.

Equipment needed to conduct the maintenance work is budgeted at $60,000. Additionally, two vehicles (probably pickup trucks) dedicated to the maintenance crews will be required, with estimated cost of $36,000.

Total estimated cost of the maintenance facility is therefore $192,000.

6-11 CENTRAL KNIFE SHARPENING AND FILING ROOM

The knife sharpening and filing room will be responsible for the tooling in all the machine centers throughout the plant. Thus knives for residue chippers, primary flaker, the shaping lathe, dowel machines, planer-matchers, moulders, and finger jointers must be sharpened, as well as bandsaws and a great variety of circular saws.

The clear-span building—which will be heated to about 65 °F in winter—will measure 30 by 60 feet (1,800 ft²) and is estimated to cost about $20/ft², or $36,000. Equipment for knife and saw sharpening is budgeted at $75,000. Also, two small utility vehicles dedicated to use by the crew operating the facility are budgeted at $20,000.

The estimated total cost of the facility is therefore $131,000.

6-12 WEIGHT SCALE

Logs on incoming trucks will be weight-scaled near the entry gate (fig. 5-2). Installed cost of a 70-foot platform scale (60-ton capacity) is estimated at $36,000. The 500-ft² office for the scale operator will cost about $15,000, yielding a total cost of $51,000.

6-13 GENERAL OFFICE

The general administrative office will have 4,000 ft² under roof, estimated to cost $40/ft², or $160,000. Furnishings and communications and computer equipment will cost another $40,000, yielding a total cost of $200,000.

6-14 SPRINKLER SYSTEM FOR ALL BUILDINGS

As noted in section 5-11, the entire plant will have 297,810 ft² under roof. All of this roofed area will be provided with sprinklers designed to reduce loss from fire. The installed cost of this entire sprinkler system is estimated as follows:

Item	Cost
40,000-gal underground water tank, installed	$ 20,000
Pumping unit with capacity of 1,000 gal/min with motor and controllers	19,000
Underground piping from water source to tank and to various buildings	40,000
Hydrants (10 at $1,500 each)	15,000
Within-building risers and sprinkler system, at $1.25/ft² x 297,810 ft²	372,000
Total	$466,000

6-15 CONTINGENCIES DURING CONSTRUCTION

A contingency fund of 5 percent of all of the foregoing costs is budgeted, that is, 0.05 x $51,175,000 or $2,559,000.

6-16 SUMMARY OF PLANT AND EQUIPMENT COSTS

From sections 6-1 through 6-16, plant and equipment costs can be summarized to total $53,738,000 as follows:

Item	Amount
Site acquisition and preparation	$ 522,000
Portal crane	1,945,000
Delimbers-debarkers and merchandisers	7,150,000
Dowel plant	893,000
Kilns	1,810,000
Joist plant	2,452,000
Plant for edge-glued panels	1,963,000
OSB plant	30,000,000
Thermal energy plant	3,400,000
Central maintenance shop	192,000
Central knife sharpening and filing room	131,000
Weight scale	51,000
General office	200,000
Sprinkler system for all buildings	466,000
Contingencies during construction	2,559,000
Total	$53,734,000

Purchase of the expensive feller-bunchers, forwarders, log trucks, and support equipment required for harvesting will be the responsibility of individual logging contractors, rather than the responsibility of the procurement corporation. Such purchases should be possible for the contractors because they will have in hand substantial contracts from the procurement corporation to deliver wood to the parent corporation. With each feller-buncher (and matching forwarder) harvesting about 218,000 trees per year, approximately 11 such machine teams will be required to harvest the 2,456,972 trees (110,000 tons of stemwood, ovendry) scheduled annually from National Forest lands.

CHAPTER 7: ESTIMATES OF CAPITAL REQUIREMENTS, OPERATING COSTS, AND BUSINESS ASSUMPTIONS UNDERLYING THE FEASIBILITY ANALYSIS

CONTENTS

7-1 PLANT LIFE

In section 2-3 under "Summary of Available Resource," it was assumed that over a 20-year plant life an annual harvest of 110,000 tons of sub-sawlog-size and dead timber would utilize 52 percent of such wood available on slopes of less than 56 percent in the National Forests within the Libby-Troy procurement area (mostly within a road radius of 75 miles); these data were based on 1986 information and assumed no growth during the 20-year period.

While the initial assumptions contemplated a 20-year plant life, it seems likely that with more-or-less continuous adjustments to meet changing resources, plant life could be extended indefinitely.

At the outset it seems unlikely that all of the remaining 48 percent of such undesirable (to conventional processors) lodgepole pine will be harvested by competitive operations. Moreover, in 20 years technology should be available to economically harvest such wood on slopes steeper than 55 percent—a resource not considered in the discussions in chapter 2. With annual harvest and regeneration of 2,000 or 3,000 acres of lodgepole pine annually (commencing with initiation of plant operation), the first of these acres regenerated should carry pines suitable for doweling 40 years from plant startup. When 40 years have passed from the first regeneration, therefore, ample wood supplies should be available to the plant.

Purchased wood of sawlog diameter—but perhaps not of sawlog quality—should continue to be available indefinitely at the level of 90,000 tons per year proposed in chapter 2 for the first 20 years of plant operation.

In summary of these introductory comments on plant life, it seems unlikely that the plant will cease operations after 20 years. For the purposes of this analysis, however, it is assumed that the plant will operate for 20 years, preceded by a 2-year preproduction development and construction period.

7-2 PLANT AND PREPRODUCTION COSTS

The proposed plant will cost an estimated $53,734,000 (including the 5 percent contingency allowance noted in chapter 6), comprised of the following components as described in section 6-16:

Site acquisition and preparation	$ 548,000
Portal crane	2,042,000
Delimbers-debarkers, merchandisers	7,508,000
Dowel plant	938,000
Kilns	1,901,000
Joist plant	2,575,000
Edge-glued panel plant	2,061,000
OSB plant	31,500,000
Thermal plant	3,570,000
Maintenance shop	202,000
Sharpening and filing room	137,000
Weight scale	53,000
General office	210,000
Sprinkler systems	489,000
Total	$53,734,000

In addition to these costs, the project requires building a log and raw materials inventory before beginning production, hiring management and sales personnel, and employing some key production workers during the preproduction period. These expenditures are estimated (see section 7-4) as follows:

Sales costs	$ 438,000
Log inventory and materials	1,375,000
Labor costs	1,128,000
Total	$2,941,000

Because the return on investment varies as the project's financing varies, two analyses were made of cash-flow and return on investment. The first used an equal mix of debt and equity to fund the project. This approximates the median of debt-to-equity ratios of publicly traded forest products firms operating in Montana. In this first analysis, additional costs associated with assumed project financing include those for underwriting, and legal and

accounting fees needed to develop long-term financing for the project—estimated at $1,663,000. Preproduction costs also include interest ($2,797,000) on the construction loan of $61,134,000.

The second analysis evaluated the project independently from the specific financing approach; that is, only the cash-flows necessary to develop the project and those derived from its operation were considered—no cash flows associated with financing were considered. The results of both of these analyses are displayed in chapter 10.

Timing of all expenditures is discussed in the following paragraphs.

7-3 CASH EXPENDITURES FOR THE PREPRODUCTION PERIOD

The preproduction period will last 2 years, but the costs just outlined in section 7-2 will not be incurred evenly throughout the 2-year period. During the first 10 months, half of the engineering and supervision costs are assumed to be incurred. The remaining engineering and supervision costs are assumed to be incurred ratably throughout the next 14 months. Building, equipment, and machinery costs are assumed to be incurred ratably during the second year. Spare parts and vehicles are assumed to be purchased during the last month of the 2-year period. Land is purchased during month 11 of the projection, and site preparation costs are assumed incurred during month 12.

Underwriter's fees will be paid at the start of year two. Legal and accounting fees will be paid monthly during year two. Some recurring operating expenditures, such as raw material purchases, labor costs, supplies, and sales costs, will be made in the preproduction period—as described in the following paragraphs.

7-4 OPERATING COSTS

As previously noted, the plant will begin production at the start of year 3. Some operating costs will be incurred prior to production; these costs are discussed in the balance of this section.

Raw Material Costs

The raw materials used by the facility are stemwood, resin for OSB, and adhesives for assembly of fabricated joists and edge-glued panels.

This analysis assumes that stemwood will be purchased beginning in month 23. In month 23, 75 percent of the monthly costs will be incurred. In month 24 and all subsequent months, a full month's stemwood will be purchased. The cost of stemwood purchases during the preproduction period will be about $1,300,000. By month 27 a full 3 months' stemwood will be on hand and maintained throughout the life of the plant. The stemwood inventory will be processed to zero during the last 3 months of the last operating year.

Included in the stemwood cost is an allowance for procurement administration. As discussed in chapter 2, it is assumed that the procurement operation will be undertaken by a separate corporation. The costs of this operation (2.6 percent of stemwood costs) have therefore been included in the cost of the stemwood. If the procurement operation were handled by the plant itself, the costs associated with procurement could be allocated to other expense and asset categories such as labor costs, supplies, and vehicles, but such allocation would not materially affect the financial analysis.

Other materials are assumed to be purchased the month before they are used based on the projected production levels of the upcoming month.

In month 24, 25 percent of a full month's inventory of material other than stemwood will be purchased. The costs of these other materials in the preproduction period will be about $75,000. In months 25 and 26, the amount of material will increase to 50 and 75 percent, respectively, of quantities needed for full production. In all subsequent months, costs will be based on full production. A 1-month inventory of materials other than stemwood will be maintained through the life of the plant, and will be processed to zero during the last month of the last operating year. Annual costs for all raw materials follow:

Stemwood	$ 8,910,000
OSB resin	2,573,000
OSB wax	378,000
Joist adhesive	430,000
Flange finger joint adhesive	71,000
Edge-glued panel adhesive	161,000
Total	$12,523,000

Labor Costs

Labor costs include those for supervisory, management, and plant labor forces. Management labor begins in month 1 of the preproduction period, supervisory labor begins in month 18, and lead plant labor begins in month 21. Labor costs include salaries and fringe benefits. The monthly labor costs for periods comprising the first 2 years are as follows:

Months 1-12	$ 18,500
13-18	32,500
19-21	81,000
22-24	156,000

The total for year 1 will be $222,000, and for year 2, $906,000. At full production the total labor cost of operating the plant will be $8,672,000 (an average of $32,000 for each of the 271 employees). The assumption is that the plant will attain full production by month 4 of year 3. Labor costs for the first year of operation will be $7,588,000. As noted above, each subsequent year's labor cost will be the base $8,672,000, adjusted for inflation.

Supplies and Services

Purchases of supplies and services consumed by the plant (exclusive of stemwood, adhesives, and wax), and of contracted services for repairs and maintenance are estimated at 1.5 percent of initial plant and equipment costs in the first year of operation, and 3 percent of initial plant and equipment costs, adjusted for inflation, for subsequent years.

Sales Costs

Sales costs incurred in marketing the various products of the operation are estimated at $875,000 annually, as follows:

Travel	$100,000
Telephone	25,000
Advertising	500,000
Miscellaneous	250,000
Total	$875,000

These expenditures are made each month beginning in month 19. Because revenues are estimated on a net f.o.b.-mill basis, cash discounts and wholesalers' commissions are not included in this tabulation of sales expense.

Sales costs for the preproduction period are estimated at $438,000.

Professional Services and Insurance

Expenditures for professional services include fees for outside auditors and legal fees. These expenses will be incurred beginning in year 3, and are estimated to total $110,000 annually.

Based on discussions with a major insurance company covering a number of large wood products facilities, estimated annual fire and liability insurance costs will be $500,000 to $750,000. A cost of $625,000 was used in the analysis.

Property Taxes

Property taxes for the proposed facility in Lincoln County were estimated with the help of Robert Holliday, Montana Department of Revenue, Property Tax Division. These estimates indicate that the tax bill should range from $800,000 to $1,200,000 per year. Property taxes cannot be estimated precisely, however, until the exact site location is known. A base figure of $1 million was used to estimate the annual property taxes.

Portions of the property tax can be waived on new Montana businesses. The most attractive waiver appears to be one that allows for the reduction of a portion of the tax, at local option, for the first 10 years of a new project. It was assumed that this local tax reduction would be obtained, and that the taxes would be as follows starting in the first year of production:

Production year	Annual property tax
1	$500,000
2	500,000
3	500,000
4	500,000
5	500,000
6	550,000
7	600,000
8	650,000
9	700,000
10-20	750,000

In the analyses, these costs were adjusted for inflation.

Utilities

Utility costs consist primarily of the cost of electrical energy to run the plant and its machinery. They will begin at the start of year 3, and are estimated at $1,491,000 per year.

Vehicles

Vehicles will be purchased at the start of the production period, and replaced every 5 years. Total cost of initial vehicle purchases is $59,000 (two vehicles each for the maintenance shop and the central knife sharpening and filing room, including contingency allowance).

7-5 PREPRODUCTION FINANCING

The plant's projected financing includes a construction loan for the first 2 years of the project. No payments on this loan will be made until the plant is finished and the company has sold a bond issue and sold stock to investors.

The construction loan will be a credit line established in the project's first month. The company will draw upon this line monthly to meet cash needs for construction and working capital until the project achieves a positive cashflow. Interest will accrue monthly at an annual rate of 10 percent.

Interest costs during construction are assumed to increase the cost of plant construction; therefore, for the purposes of this projection, they will be capitalized and allocated with 20 percent to buildings and 80 percent to equipment. These amounts will be added to the depreciable basis of the project.

7-6 LONG-TERM FINANCING

The construction loan will be paid off at the end of year 2 with proceeds of a stock sale and bond issue undertaken during year 2. For this projection it is assumed that all the funds from these financing efforts, less the amount of the construction loan and preproduction costs, will be available at the end of year 2 as working capital for the initial production period.

Sales of stocks and bonds to investors will each provide $31 million, for a total of $62 million. Underwriter fees to be paid during the first month of year two will be $930,000 for the stock sale and $233,000 for the bond sale.

Accounting and legal expenses related to the issue of stocks and bonds are estimated at $500,000, divided equally between the stocks and the bonds. All expenses relating to the bond issue are capitalized and amortized over the life of the bonds. Fees relating to the stock issue are not deductible for tax purposes.

The bonds will have a 20-year life; the interest rate is assumed to be 10 percent. The bonds will be paid off in equal installments, 6 months apart, with the first payment to be made in the sixth month of the third year. This semiannual payment will be $1,807,000.

7-7 REVENUE

As described in section 3-3, estimated annual net sales with the plant operating at full production (100 percent of rated capacity) will be $38,197,000. It is assumed that the plant will have achieved full production and sales by month 4 of the first year of production. Estimated net sales revenue in this first year is $33,420,000. For subsequent years it is assumed that revenue will be $38,197,000 adjusted by the appropriate inflation rate.

7-8 DEPRECIATION

For purposes of this projection, tax depreciation is assumed to equal accounting depreciation. Tax depreciation methods follow the modified accelerated cost recovery system (MACRS) methods required by the 1986 Tax Reform Act. All depreciation begins at the first month of year 3, with depreciable lives according to MACRS ranging from 5 to 31.5 years.

7-9 INFLATION FACTORS

Revenue is assumed to increase by 4.5 percent per year, based on Wharton Econometrics long-term forecasts for prices of lumber and wood products for the period 1988-2007 (Wharton 1987).

Expenses subject to inflation are assumed to increase by 3.6 percent per year, based on Wharton Econometrics forecasts for the Producer Price All-Commodities Index. The expenses considered subject to this inflation factor are raw materials, labor, supplies and services, sales costs, professional services, property taxes, utilities, and vehicles.

7-10 ACCOUNTS RECEIVABLE

Revenues are assumed to be collected in the month after they are earned. Accounts receivable are therefore assumed equal to 1 month's sales. For cash-flow and tax purposes the amounts in the accounts receivable balance are one-twelfth of the current year's sales.

7-11 TAX RATE

The applicable income tax rate is assumed to be 40.75 percent, including both Federal and State levies.

7-12 LIQUIDATION

For the purposes of this projection (see the introductory paragraph in this chapter for comments on plant life), it is assumed that assets are sold or written off at the end of year 22 (production year 20). The land's sale value will be its cost, increased by the projected change in the Producer Price All-commodities Index. Depreciable assets will be written off, creating a tax benefit. Raw-material inventories will be utilized in the operation's last months.

7-13 REFERENCE

Wharton Econometrics Forecasting Associates. 1987. U.S. long-term forecast annual model. Bala Cynwyd, PA: Wharton Econometrics Forecasting Associates: 1-87.

CHAPTER 8: SHIPPING COSTS

CONTENTS

Potential plant sites are on the Burlington Northern main east-west rail line, and adjacent to U.S. Highway #2 in the Libby-Troy area. The Union Pacific rail system can be accessed a few miles west at Moyie Springs, ID, or more distantly in Butte, MT (figs. 2-4, 2-5, and 8-1). For rail access to the Butte connection with the Union Pacific, transfer of cars from the Burlington Northern for a short intermediate haul via Montana Rail Link—a several-hundred-mile rail line through southern Montana recently severed from Burlington Northern—is required from Sandpoint, ID, to Butte; alternatively, wood can be truck-hauled to Moyie Springs for loading on the Union Pacific line, or truck hauled to Noxon, MT, for shipment via Montana Rail Link to the Union Pacific connection at Butte.

The Interstate Highway System (fig. 8-2) is most conveniently accessed at Spokane, WA, Missoula, MT, or Shelby, MT. Major markets are, for the most part, distant from northwestern Montana (table 8-1).

The nearest salt water port is Seattle, WA—439 miles from Libby. A barge-loading facility, with access to the Pacific, is located in Lewiston, ID, at the head of navigation on the Snake River and 263 highway miles from Libby.

8-1 TRUCKING COSTS

Since deregulation, the cost of trucking wood products to market has diminished; while these costs can be estimated (table 8-1), the actual cost can be determined only by negotiation for a particular hauling contract.

In general, however, truck transport to most western and southwestern markets is competitive with rail transport—particularly to customers not located on a rail siding (table 8-1). Additionally, truck transport affords prompter delivery than is usually possible by rail. Truck delivery also provides a mechanism for minimizing inventories in distributing yards because trucks typically have a net load of only 25 tons, and the cargoes can readily be offloaded at two or more locations, whereas rail cars typically carry 40 to 90 tons of cargo and are less conveniently delivered to more than one customer.

8-2 RAIL TRANSPORT COSTS

Because the projected plant location is on the Burlington Northern rail line, virtually all rail shipments will move via Burlington Northern. On this line, all of the commodities the plant will produce are subject to the same tariffs. These published tariffs for boxcar shipments (table 8-1) are typically higher than the rates achieved through haul contract negotiation; for ease of reference, 25 percent reductions in the published tariffs are tabulated (table 8-1).

The fabricated joists, which will usually be rail shipped in 64-foot lengths, will move on flatcars rather than in boxcars, but the rate will probably not be appreciably different.

For the distant markets in the South and Southeast, lower published tariffs apply if shipments are made in 40-foot containers via rail piggyback, as follows:

Destination	Dollars per ton
Atlanta	94
Houston	88
Jacksonville	110
Memphis	82
Miami	127
New Orleans	95

The minimum weight per container is only 40,000 pounds. In addition to the published tariff tabulated above, however, there is a $4 charge per container to load and unload it.

Two by four studs, which comprise only a small portion of the plant output (about 4 million bd ft annually), might be shipped via the Union Pacific rail line in Moyie Springs, ID. Union Pacific rates for boxcars or flatcars are particularly favorable to the Salt Lake City market area ($26/ton published tariff with estimated $20/ton contract price per ton). The cost of truck transport from the plant site to Moyie Springs would add an additional $2 or $3/ton to the shipping cost of the studs.

8-3 COST OF WATER-BORNE SHIPMENT

Three destinations are of particular interest when considering water-borne shipments: Los Angeles, Osaka, and Shanghai.

It seems unlikely that wood products could be trucked from the Libby-Troy area some 263 miles to the Snake River, loaded on barges and floated to salt water, and then transloaded to oceangoing ships at a price competitive to trucking the 439 miles to Seattle for direct loading onto oceangoing vessels. When oceangoing ships can be direct-loaded at Lewiston, ID, Snake River transport to salt water may be competitive, however.

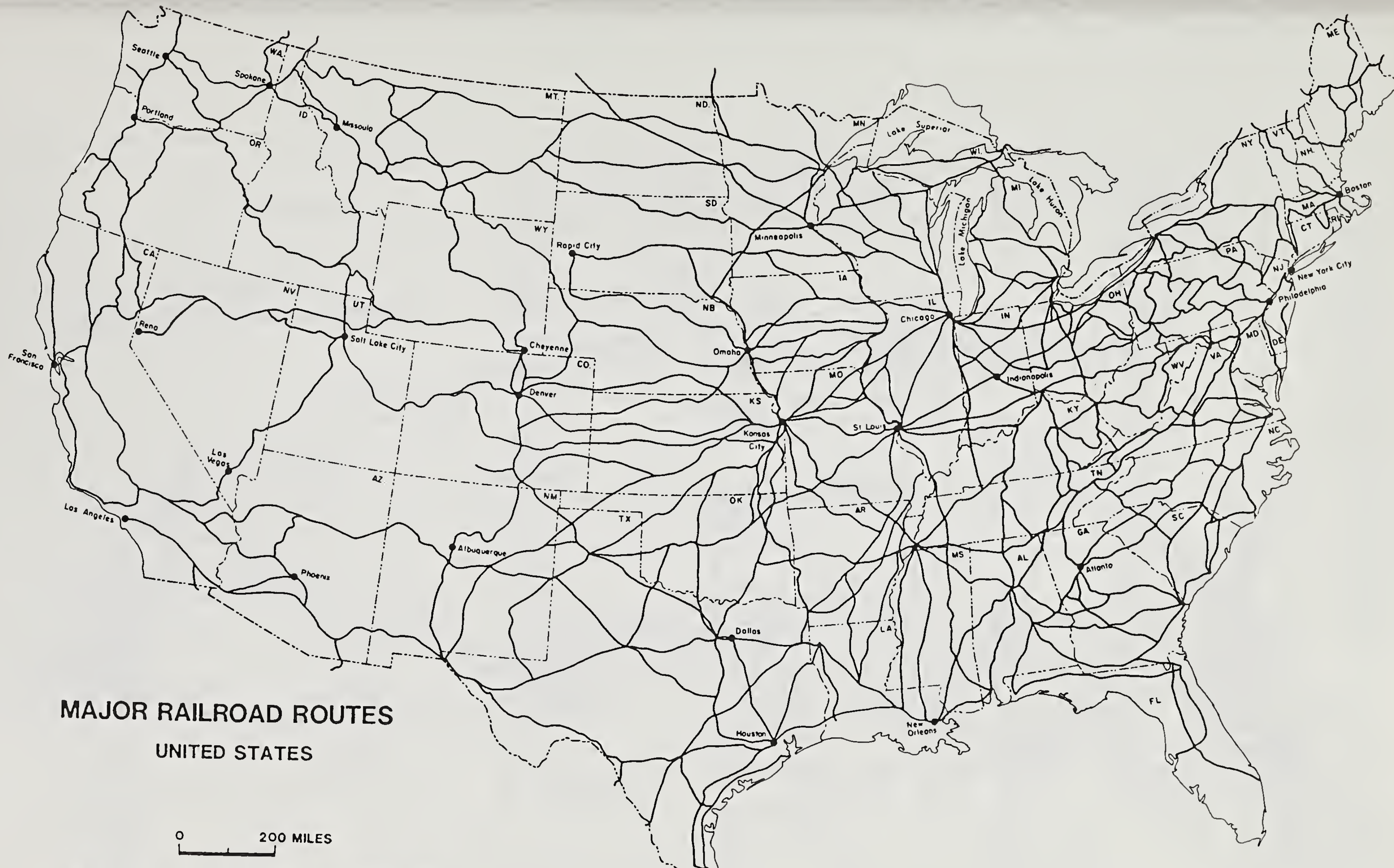

Figure 8-1—Major railroad routes in the United States.

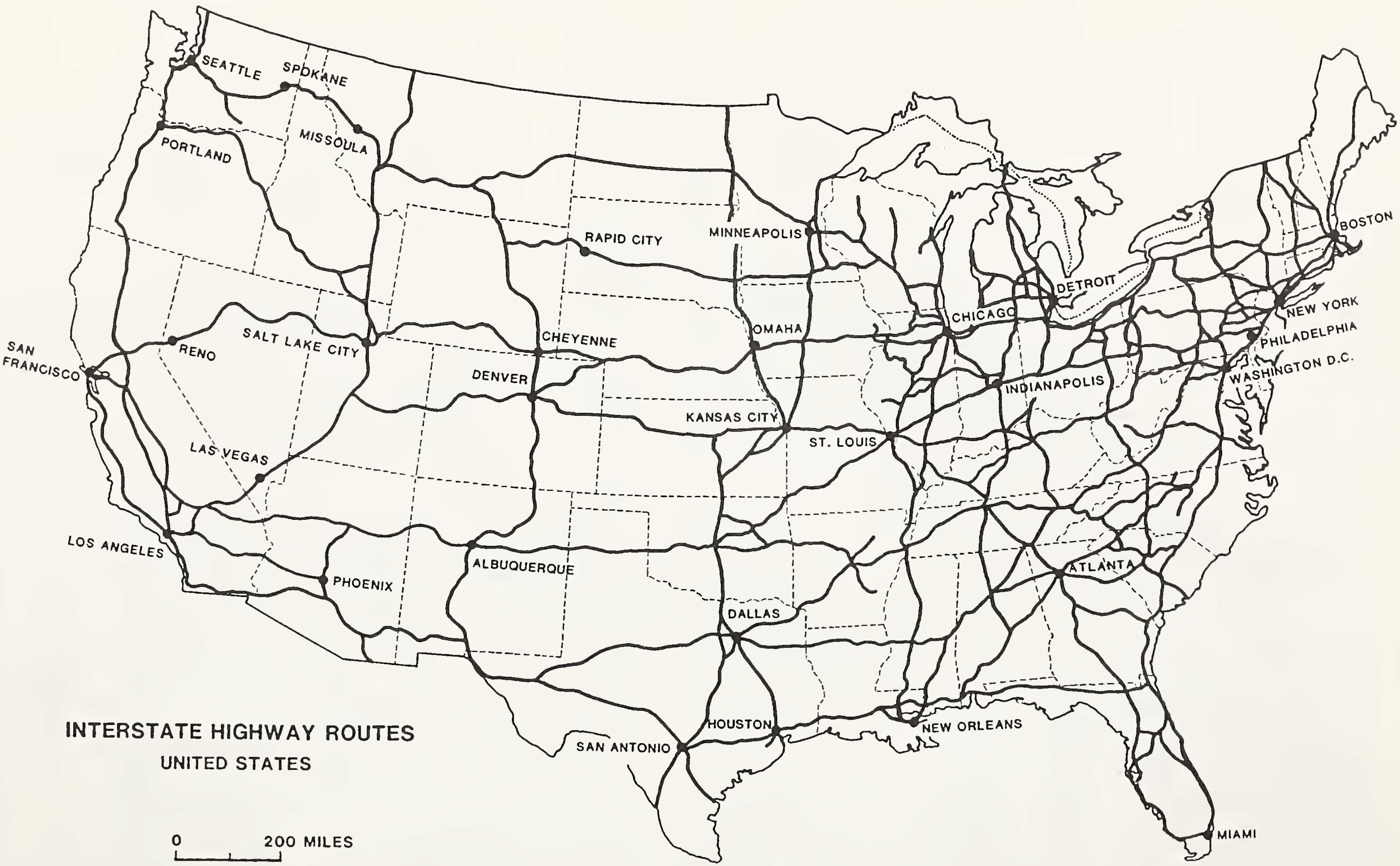

Figure 8-2—Interstate Highway System in the United States.

Table 8-1—Highway distances from Libby, MT, to 27 cities representing major markets in the United States, and estimated freight costs by truck and Burlington Northern boxcar (OSB, joists, edge-glued panels, and dowel products)

Region and city	Miles	Freight cost via truck[1]	Freight cost via rail boxcar: Published tariff	75 percent tariff[2]	Minimum weight
		Dollars per ton			Pounds
West					
Denver	1,081	54	31	23	110,000
Portland	509	25	32	24	90,000
Salt Lake	704	35	49	37	85,000
San Francisco	1,201	60	63	47	85,000
Seattle	439	22	25	19	100,000
Spokane	153	8			
Southwest					
Dallas	1,856	93	50	38	110,000
Las Vegas	1,113	56	59	44	85,000
Los Angeles	1,378	69	63	47	85,000
Phoenix	1,352	68	84	63	85,000
Reno	972	49	63	47	85,000
Midwest and East					
Boston	2,690	135	49	37	110,000
Chicago	1,727	86	49	37	110,000
Cleveland	2,057	103			
Kansas City	1,553	78	44	33	110,000
New York	2,524	126			
Omaha	1,352	68	37	28	110,000
Rapid City	848	42			
St. Louis	1,790	90	53	40	110,000
St. Paul	1,332	67	35	26	110,000
Washington DC	2,393	120			
South and Southeast					
Atlanta	2,327	116	114	86	95,000
Houston	2,089	104	95	71	95,000
Jacksonville	2,633	132	117	88	95,000
Memphis	1,999	100	95	71	95,000
Miami	2,982	149	131	98	95,000
New Orleans	2,330	117	97	73	95,000

[1]Based on $1.25 per loaded mile with a payload of 25 tons.
[2]Contract prices are typically significantly lower than published tariffs.

Rail shipping costs to the Seattle port will be about $19/ton, and to the Portland port about $24/ton (table 8-1).

Shipping in 40-foot containers seems practical for doweled products like tree props, and for edge-glued lumber panels. As discharged from the hot press, OSB and oriented-strand lumber will measure 8 feet wide and 32 feet long; such large panels could be loaded in 40-foot containers for remanufacture to desired dimension at destination—for example to metric dimension in Japan or China. Alternatively, sizing of panels and oriented-strand lumber could be accomplished at the Montana plant, and these smaller panels containerized for shipment to market. Because the fabricated joists are best transported to market in long lengths (64 feet) and cut to length at a distribution yard, containerized shipment may not be practical unless lengths are limited to less than 40 feet.

The primary target for containerized shipments could be OSB in large panel sizes (8 by 32 feet) for remanufacture in destination cities. A single 40- by 8- by 8-foot container could hold 200 such panels each weighing about 400 pounds, for a total cargo weight per container of 40 tons. A more likely weight, however, is 20 tons—which is the minimum container weight for economic rail transport, and which is light enough to be moved by truck from destination port to distribution yard. Maximum permissible container weight is generally 24 tons.

If Los Angeles, Osaka, or Shanghai could be developed into a major market, as many as 2,000 such 20-ton containers could be shipped annually. With this volume of shipment, rates per container (and per ton of OSB) from Portland—including loading and offloading charges—would be about as follows (the rail cost is estimated at $24/ton to Portland; the transport cost from destination port to distribution yard is estimated at $6/ton):

Destination	Ocean transport cost per 20-ton container, including loading and offloading	Ocean transport cost per ton	Land transport cost per ton	Total cost per ton
	Dollars			
Los Angeles	250	13	30	43
Osaka	1,100	55	30	85
Shanghai	2,350	118	30	148

Container service by ocean freight from Portland to Los Angeles was not available in December 1987, but should the service be started, the rate shown would be approximately correct. Loading and offloading costs per container in Shanghai are unavailable, but the tabulation includes $50 for this purpose.

8-4 SHIPPING WEIGHT OF PRODUCTS

Tree Props

Tree props turned green to 2 inches in diameter weigh about 0.61 pound per lineal foot (0.31 ton per thousand lineal feet) when dried to 10 percent moisture content, at which time they measure about 1.9 inches in diameter. This corresponds to a shipping weight of 31 lb/ft^3.

Studs

A thousand board feet (1,500 lineal feet or 54.69 ft^3) of studs dried to 10 percent moisture content and planed S4S should weigh about 1,727 pounds, or 0.86 ton.

Edge-Glued Panels

Edge-glued panels also weigh about 31 lb/ft^3, including adhesive, at a shipping moisture content of 8 percent of ovendry weight. This corresponds to a shipping weight of 1,938 pounds (0.97 ton) for 1,000 bd ft (500 ft^2) of 1.5-inch-thick panel.

Fabricated Joists

Including adhesive, fabricated joists shipped at 10 percent moisture content will weigh as follows:

Size	Per lineal foot	Per 1,000 lineal feet	Per 1,000 nominal board feet
	Pounds	*Tons*	*Ton*
2 by 10	2.9	1.45	0.87
2 by 12	3.1	1.55	.78
2 by 14	3.3	1.65	.71
2 by 16	3.5	1.75	.66

Oriented-Strand Board

Oriented-strand board, including adhesive and wax content, shipped at 8 percent moisture content, will weigh about 44.2 lb/ft^3. This corresponds to 1,381 pounds (0.69 ton) per M ft^2 of $^3/_8$-inch-thick panels and 1,611 pounds (0.81 ton) per M ft^2 of $^7/_{16}$-inch-thick panels.

Oriented-strand lumber 1.5-inch thick, including adhesive and wax, shipped at 8 percent moisture content, will weigh about 40 lb/ft^3. This corresponds to the following shipping weight per M bd ft of product ripped to standard lumber widths:

Nominal lumber size	Weight/M bd ft	
Inches	*Pounds*	*Tons*
2 by 4	2,188	1.09
2 by 6	2,292	1.15
2 by 8	2,250	1.13
2 by 10	2,312	1.16
2 by 12	2,344	1.17

CHAPTER 9: MARKETS, PRODUCT SELLING PRICES, AND DISTRIBUTION METHODS

CONTENTS

9-1 GEOGRAPHIC AND DEMOGRAPHIC CONSIDERATIONS

Foreign and Domestic Timber Supplies

A report of this scope cannot deal exhaustively with the timber supply-demand system of the world, but some general comments are appropriate. It is well accepted that the large-timber resources of the world are being rapidly harvested; much of this large-tree resource is being replaced by trees that will be of fairly small diameter when harvested. In the United States, the old-growth Douglas-fir, hemlock, Sitka spruce, sugar pine, western white pine, ponderosa pine, and western redcedar of the West are being depleted and replaced by second-growth timber that will likely have average diameter at breast height (d.b.h.) of 16 inches or less when harvested. The large old-growth southern pine trees of the South—and the eastern white pine trees of the North Central and Northeastern States—have been, for the most part, liquidated and replaced by second-growth trees that will average perhaps 12 inches in d.b.h.

Current harvesting and management practices in Canadian forests will similarly yield small-diameter trees in the Canadian forests of the future.

The coniferous forests of Europe are largely in stands managed to yield trees of moderate size—averaging perhaps 13 inches or less in diameter when harvested.

While the coniferous forests of Russia are vast, much of the resource—particularly in Siberia—is remote and is considered by many to be uneconomic to harvest and sell in world markets in the next two or three decades. For this reason, Russian timber sales will likely not be a strong depressant on world prices for logs during the life of the plant under consideration in this report.

For two reasons the large hardwood logs from Southeast Asia and the South Pacific regions are becoming largely unavailable to consuming industries in the rest of the world. First, the supply of such large logs is being depleted, and second, the countries of origin are increasingly legislating against export of logs—instead favoring internal manufacture of wood products for export.

The exotic pines—principally *Pinus radiata* and the southern pines—in the extensive coniferous plantations of the southern hemisphere (for example, in New Zealand, Chile, Australia, and Brazil) are largely managed on short rotations yielding relatively small-diameter trees.

In summary, it seems likely that commercial world forests of the future will not be predominantly comprised of large-diameter trees, but instead will hold trees generally 10 to 16 inches in d.b.h. when harvested. This suggests that the long wide structural lumber, and the wide thick clear lumber characteristically yielded by old-growth trees will be less readily available in world trade—and will be replaced in large degree by fabricated or reconstituted wood products such as the fabricated joists (figs. 3-2 and 3-3), edge-glued panels (fig. 3-5), and OSB (fig. 3-6) discussed in chapter 3.

The foregoing comments are not intended to imply that the overall harvest of timber will diminish in the next several decades, but simply that average log diameter will diminish.

Export vs. Domestic Markets for Manufactured Wood Products

The market for coniferous logs exported from western North America to Pacific Rim countries—principally to Japan, but also to Korea, Taiwan, and China—developed strongly in the last 15 to 20 years, and was particularly robust during mid-1987. These logs are transported in bulk-loaded ships typically with five holds each accommodating two 40-foot log lengths and totaling perhaps 1,160,000 ft^3, and carrying 25,000 tons. Ships of this capacity might be chartered in 1987 for about $450,000 to carry logs from the West Coast of North America to Japan, Korea, or the People's Republic of China; such a charter would typically require 1 day for loading, 14 days in transit, and 1 to 3 days to offload. Longer charters—for example to Turkey (requiring 1 day to load, 23 days in transit, and 1 day to offload)—might cost $760,000.

Log diameters specified by customers in these countries are generally greater than diameters available from the lodgepole pine forests of the Rocky Mountain Region, although there might be a modest market for small utility poles (40 feet long with 4-inch minimum top diameter and at least a 7-inch butt).

Export volumes to Pacific Rim markets of West Coast coniferous logs exceed lumber exports of these species by 4:1 or 5:1. Few timber merchants in the export business believe that products manufactured from small inland species (such as lodgepole pine) can find a major place in the export trade. These merchants believe that only very high-value products (for example those with a domestic value of near $1,000/M bd ft) can originate in the Rocky Mountain Region and can be sold in the export market. Such products would be shipped in 20- or 40-foot-long containers, with rates per container such that shipping cost per ton of product might be $85 to Japan and $148 to China ports (see section 8-3). In China, only certain ports are equipped to receive containers; such ports would include Xingang (near Beijing), Shanghai, Canton, and Dalian (near Tianjan and Beijing).

It is difficult to find markets for even these high-value products because virtually all of the Pacific Rim potential customers desire to convert logs to products, rather than import the products. Niche markets are present, however; for example, log cabin manufacturers in the Bitterroot Valley of Montana have been successful in obtaining significant orders from merchants in Japan.

In summary of these comments on the potential for export versus domestic markets, knowledgeable timber merchants are nearly unanimous in believing that the United States should receive primary emphasis in any strategy to market products produced from lodgepole pine in the Rocky Mountain Region.

Population Distribution in the United States Related to Freight Rates

Study of freight rates (table 8-1) suggests that commodities priced to be competitive with a freight rate of $30/ton or less will be limited to a market radius including Denver, Portland, Seattle, Salt Lake (via the Union Pacific), Omaha, and St. Paul-Minneapolis. If the market price can absorb a $31 to $37 per ton rail freight rate, the major markets of Kansas City, Chicago, and Boston can be accessed. Only by paying rail freight charges of $38 to $47 per ton can markets in Dallas, St. Louis, San Francisco, Los Angeles, Reno, and Las Vegas be reached.

It is obvious from study of population distribution in the United States (fig. 9-1) that the market reachable with a $30 freight rate is very small compared to that encompassed by a $37 or $48 ceiling on rail rates.

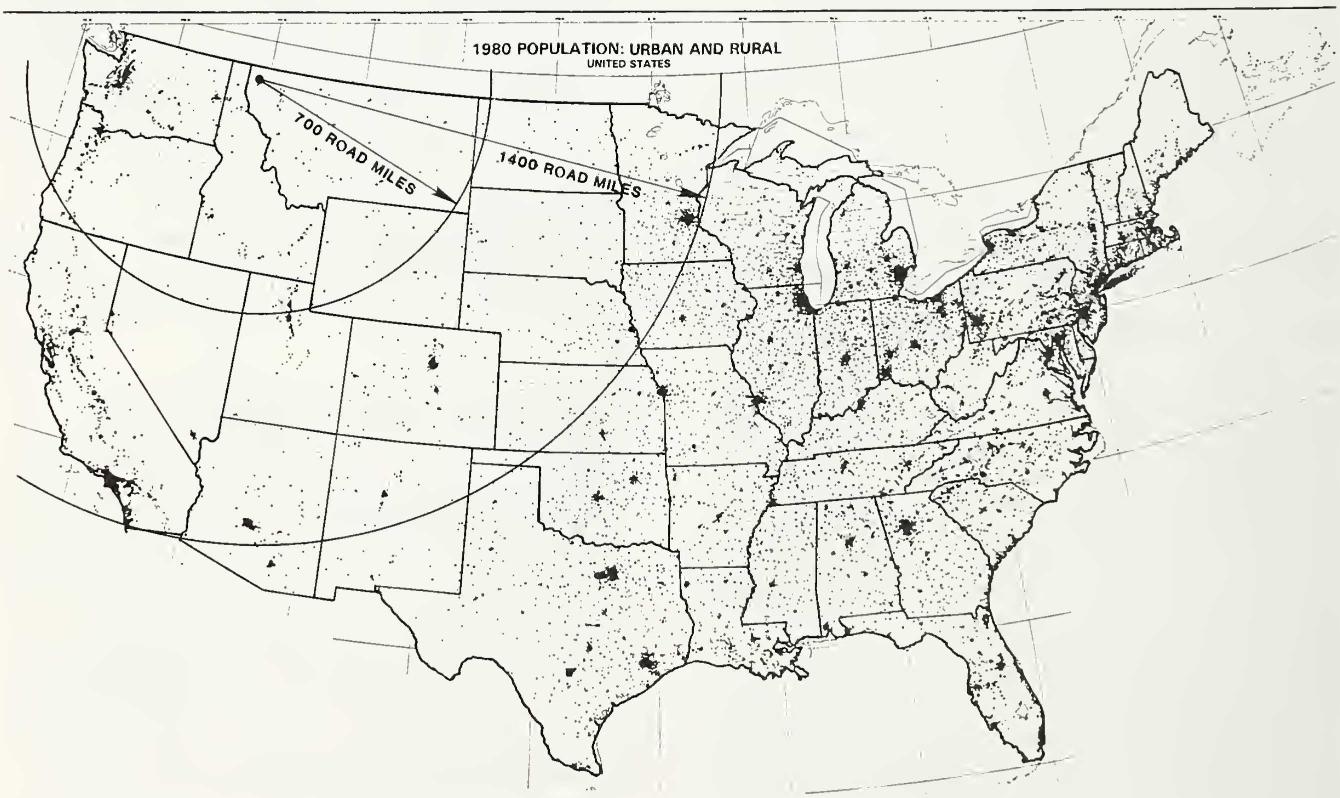

Figure 9-1—Population distribution in the United States with 700- and 1,400-mile highway-distance radii (approximate) from the Libby-Troy area indicated.

Table 9-1—Summary of annual product volumes, prices, and annual sales

Product	Annual output	Price per unit	Net annual sales
		Dollars	
2-inch tree props	2 million pieces averaging 9 feet long	0.095/ lineal foot	1,710,000
2-5/8-inch tree props and rails	520,000 pieces averaging 14 feet long	0.15/ lineal foot	1,092,000
10-inch-deep fabricated joists	6,850,000 lineal feet	0.66/ lineal foot	4,521,000
12-inch-deep fabricated joists	13,700,000 lineal feet	0.72/ lineal foot	9,864,000
Edge-glued panels	6,500,000 ft^2 (1.5-inch-thick basis)	750/M ft^2	4,875,000
2 by 4 studs	4 million bd ft	181/M bd ft	724,000
Market OSB	117,500,000 ft^2 of 7/16-inch sheathing	130/M ft^2	15,275,000
Pulp chips	6,500 tons, ovendry basis	18.33/ ovendry ton	119,000
Particleboard furnish	14,379 tons, ovendry basis	1.00/ton	14,000
			38,194,000

For some products, notably tree props, the major market (southern California) is accustomed to delivery by truck with freight rates as high as $69 per ton (to Los Angeles). Unfortunately, the two counties in the United States with the greatest population increases since 1980 are expensive to reach by rail; the rate to Los Angeles County in California is $47 per ton and the rate to Maricopa County in Arizona (Phoenix environs) is $63 (table 8-1).

With the foregoing information and summary price and production data (table 9-1) in mind, discussions of markets, product selling prices, and distribution methods for the various products follow.

9-2 TREE PROPS

Markets

The market for lodgepole pine tree props (fig. 3-1) was expanded greatly by North Idaho Post and Pole and associated marketing companies selling to large landscape supply houses in California. This company, with production facilities in Hayden Lake, ID, is probably the major seller of lodgepole pine tree props and related pole products for agriculture. Lodgepole pine, because of its good stem form, small knots, and high strength-to-weight ratio, is the major species utilized for tree props. While many tree props are sold untreated, most are probably treated with preservative—sometimes at the originating plant and sometimes in transit near the point of use.

Other major producers of lodgepole pine doweled tree props, all with manufacturing plants in Montana, include Bouma Post Yards, Lincoln (with facilities to pressure-treat products with chromated copper arsenate); Desert Mountain Forest Products, Glacier; Flathead Post and Pole Yard, Dixon (with soak tanks to impregnate products with pentachlorophenol in oil); and Grizzly Timber Products and Nine Mile Posts and Rails, both near Missoula.

In aggregate these Idaho and Montana producers have 10 or 12 doweling machines in operation producing tree props—usually on a one-shift-per-day basis, but sometimes operating two or even three shifts.

As noted previously, the major market for tree props is in California, with smaller sales in other southwest markets such as Reno, Las Vegas, and Phoenix. Little effort has been made to develop markets in the Midwest. If markets in the Deep South are to be developed, it is probable that the props would have to be incised to insure preservative retention adequate to withstand the decay and termite hazard present in this market area.

Conversations with producers suggest that the market, while finite, is not yet fully developed. In the plant under consideration in this analysis, only one doweling machine is contemplated—but it would be scheduled for three-shift operation, probably 7 days a week. With vigorous sales efforts and competitive pricing, it seems reasonable that the market will easily absorb the output proposed.

Product Selling Prices

Wholesale prices for untreated 2-inch diameter tree props have declined somewhat during the last several years from about $0.125 per lineal foot to about $0.10 per lineal foot f.o.b. Montana or Idaho plants. In the plant under study, a net price of $0.095 per lineal foot (after all discounts and commissions) f.o.b. plant is proposed. Costs of treating with chromated copper arsenate would be done in transit at extra cost.

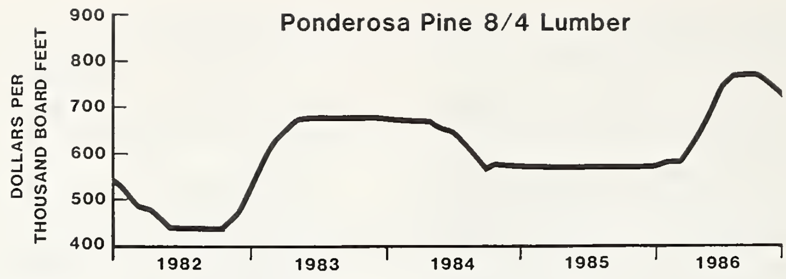

Figure 9-2—Five-year price trend for ponderosa pine kiln-dry 8/4 #2 shop lumber, net f.o.b. mill. Data from Random Lengths (Richards 1987).

Some props $2^5/8$ inches in diameter would also be produced in conjunction with manufacture of flanges for fabricated joists. The net f.o.b. mill price proposed for these larger props and rails is $0.15 per lineal foot.

Distribution Methods

Lodgepole pine tree props have gained such acceptance in certain markets that one of the several major distributors of wood products should find it profitable to sell the entire output of the proposed plant. Strength of props from northern Montana should be superior to those from sources in more southerly latitudes (see section 4-1), so it should be possible to maintain product superiority over potential competitors to the south.

Lacking such a sales agreement, it seems likely that one inhouse salesperson could market the plant output of tree props.

9-3 EDGE-GLUED PANELS

Markets

The edge-glued panels proposed (fig. 3-5) will contain the small knots characteristic of lodgepole pine. Although the stem sections for conversion to edge-glued panels will have been visually graded and selected for sound red knots, it seems likely that two grades of panels will result—a sound red-knot grade, and a sound black-knot grade. Also, the panels will be made available with either a colorless glue line for interior applications, or with a dark glue line for exterior uses.

Millwork manufacturers in the United States are accustomed to using clear cuttings made from shop grades of ponderosa, western white, and sugar pines—but thick planks of shop grades of these pines will inevitably become scarcer and more expensive with the passing of years and liquidation of the very large trees which yield such wood. For this reason, it is likely that more economical wood containing small knots will become acceptable for many millwork uses. If such wood is available in specified thicknesses, widths, and lengths, economies in raw material utilization and manufacturing procedures should be achievable.

Manufacturers in Finland, West Germany, and Japan have installed plants to produce panels similar to that illustrated in figure 3-5. In these countries uses for the panels include the following:

bed headboards	plinths
bedrails	school desk lids
benches	shelves
cabinet doors	shutters
chair seats	stair rails
chairs	stair treads
door frames	table tops
doors	truck flooring
garage door rails	turnings
garage door stiles	wall panels
garden furniture	window frames
load-bearing wood	windowsills
lockers	wooden toys
office desks	work tops
playground furniture	

Because annual product output (table 9-1) is only on the scale of a very small sawmill, the proposed operation would need to capture only a miniscule share of the market in the United States for knotty grades of the products in the foregoing list.

It is contemplated that most sales will be of rectangular blanks of specified length, width, and thickness; the industrial user will then fabricate these blanks (by moulding, turning, shaping, and perhaps veneering) into the products of choice. Moisture content at shipment will be about 8 percent of ovendry weight. By the nature of log selection and panel assembly (fig. 3-5), the growth rings will be closely spaced—averaging less than one-sixteenth inch in width—and oriented so that width and thickness shrinkage will be intermediate between values for pure radial and tangential shrinkage; that is, the extreme width shrinkage characteristic of wide flat-sawn lumber will be avoided in the proposed edge-glued panels.

Product Selling Prices

Because sound-knotted edge-glued panels of the type contemplated are not now a commonly accepted commodity in commerce, the price obtainable is difficult to estimate. As suggested in earlier paragraphs, shop-grade

lumber brings a high price and, because of decreasing availability of large-diameter trees, can be expected to increase in price in the future. For the years 1982 through 1986, the price for kiln-dry ponderosa pine 8/4 #2 shop lumber averaged $591/M bd ft net f.o.b. mill (fig. 9-2). Shop lumber in 8/4 thickness has a surfaced thickness of $1^{13}/16$ inches; this price amounts to $1,182/M ft² of such lumber. If this ponderosa pine lumber were produced at a net thickness of 1.5 inches and equivalently priced, the price per square foot should be $978/M ft². But, of course, shop ponderosa pine—a cutting grade—is not directly comparable to the sound-knotted panels proposed that are intended for use in their entirety.

Blanks for garage door rails and stiles that permit inclusion of sound knots are perhaps a better indicator of prices obtainable for blanks cut from the proposed sound-knotted lodgepole pine panels. Industry is currently offering about $1.80 for a sound-knotted blank 9 feet long, 1.375 inches thick (scaled as 6/4), and 3.375 inches wide (scaled as 3.5 inches to include kerf). This price per piece is equivalent, based on cubic content including kerf to rip, to about $750/M ft² of 1.5-inch-thick panel.

Another clue to the price obtainable is the wholesale price of 1.5-inch-thick laminated truck flooring, which brings about $1,800 per thousand lineal feet of pieces 16 inches wide, or $1,350/M ft². Truck flooring is a sound-knotted product, but because it is mainly made in long lengths with finger-jointed components of Douglas-fir and larch, it is not exactly comparable to the proposed product.

From study of the price data available, it seems conservative to use in this feasibility analysis a price of $750/M ft² for panels sanded to 1.5 inch thickness. Obviously, price per square foot will vary with thickness and panel grade, but the price noted is considered an average attainable price net f.o.b. mill.

Distribution Methods

It is evident from the previously listed products that could potentially utilize the edge-glued panels that sales efforts must be concentrated on the industrial sector, rather than on retail lumber yards. Close direct communication between seller and buyer is needed to serve such industrial markets. It is proposed, therefore, that half the sales of the edge-glued panels—and blanks cut from them—be handled by an inhouse salesperson and the balance through wholesalers. Because of the high value of the edge-glued panels, it is likely that freight costs will not be an insurmountable barrier to Midwestern and Southwestern markets.

In addition to the industrial panels, some significant volumes of shrink-wrapped shelving products could likely be sold to the "shoulder trade" through retail lumber yards.

9-4 STUDS

Markets

Two-by-four 8-foot studs are one of the major wood commodities sold in the United States. Well-manufactured kiln-dry lodgepole pine studs find a ready market if competitively priced. Because the production volume contemplated (table 9-1) is miniscule in relation to the size of the market, the studs should be salable within the market area encompassed by a $30/ton rail freight rate, that is, including Denver, Salt Lake, Portland, Seattle, Omaha, and St. Paul-Minneapolis.

Product Selling Prices

Fluctuations in stud prices have been considerable (fig. 9-3). For the 5 years 1982 through 1986, kiln-dry spruce and lodgepole studs have averaged $181/M ft² net f.o.b. mill. This average price has been used in this feasibility analysis.

Distribution Methods

Distribution through a wholesaler is probably the most economical way of marketing the studs.

9-5 FABRICATED JOISTS

Markets

In the United States, annual western (including Rocky Mountain) production of #2 and better lumber of all coniferous species totals about 1.674 billion bd ft of 2 by 10's and 1.097 billion bd ft of 2 by 12's. Annual production of southern pine 2 by 10's and 2 by 12's is about 0.650 billion bd ft. It is difficult to say what proportion of this output is utilized for floor and ceiling joists, but perhaps half the output goes to these uses.

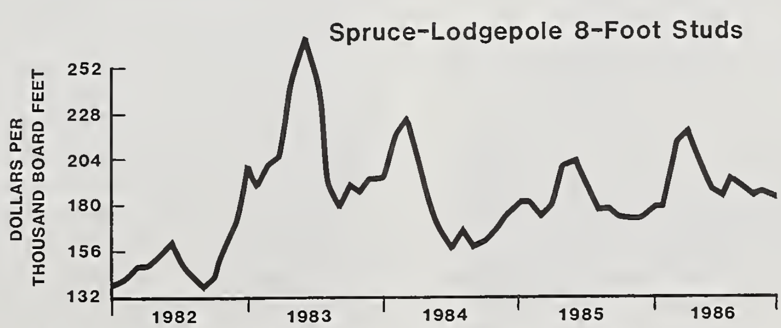

Figure 9-3—Five-year price trend for spruce-lodgepole kiln-dry 2 by 4 studs 8 feet long. Data from Random Lengths (Richards 1987).

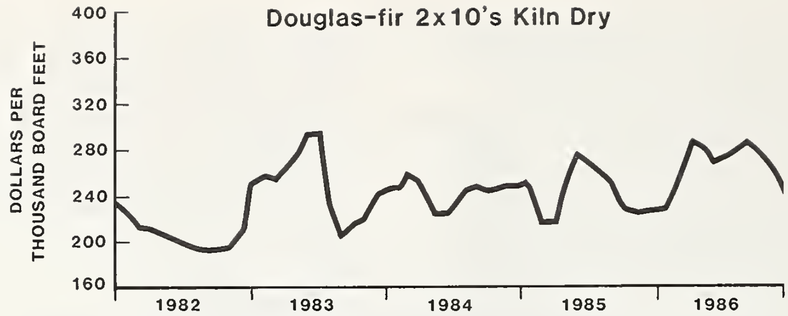

Figure 9-4—Five-year price trend for kiln-dry Douglas-fir #2 and better random-length 2 by 10 lumber, net f.o.b. mill. Data from Random Lengths (Richards 1987).

The proposed production of fabricated joists (table 9-1), while only about 1 percent of the lineal footage of structural 2 by 10's and 2 by 12's produced in the United States, is still a significant volume to market.

The proposed joists, because they are significantly lighter, drier, stiffer, stronger, and more uniform in mechanical properties than sawn lumber joists, should—over time—gain enthusiastic acceptance by builders. One of their most compelling advantages is quick availability from distributing yards in schedules of precise, but nonstandard, lengths specified by the builder. Additionally, the joists will be made under strict quality control and shipped at a uniform low moisture content of about 8 percent of ovendry weight. Close control of moisture content not only results in a lighter product compared to sawn lumber, but minimizes shrinkage in depth and thickness. In contrast, excessive shrinkage in incompletely dried sawn joists can cause significant problems for builders and building occupants.

In the past, sales of competitive fabricated joists for residential and light commercial construction were heavily concentrated in 10- and 12-inch depths, but recently 14- and 16-inch joists are in demand. Conversations with major distributors of fabricated joists suggest that consumption of lineal footage by depth is about as follows:

Nominal joist depth	Percentage of lineal feet sold
Inches	
10	15
12	51
14	22
16	12
	100

Although most of the discussion in this analysis has been focused on 10- and 12-inch joists, it is evident that the plant must also produce joists 14 and 16 inches in depth.

As this analysis has proceeded, funding has not proved sufficient to conduct the product and market analyses that would assure success in marketing the joist output of the proposed plant. Because commercial acceptance of the joists is so critical to the financial success of the plant, and hence the utilization and reforestation of the public forest stands at issue (see section 1-4), we believe USDA funding for market analysis is merited. To date such funding has not been allocated, however.

Product Selling Prices

The price of kiln-dry Douglas-fir 2-by-10, #2 and better, random-length lumber has fluctuated significantly in recent years but during the 5-year period 1982 through 1986 has averaged $259/M bd ft net f.o.b. mill (fig. 9-4), or $0.43 per lineal foot.

The price of fabricated joists has been very stable at a considerably higher price per lineal foot. The major manufacturer of fabricated joists prices 9.5-inch-deep joists at about $0.735 per lineal foot and 11.875-inch-deep joists at about $0.804 per lineal foot, net f.o.b. western mill after all discounts and commissions.

For the purposes of this analysis, joists produced by the proposed plant are priced 10 percent lower, that is, $0.66 per lineal foot for joists 10 inches deep, and $0.72 for joists 12 inches deep; both prices are net f.o.b. mill after all discounts and commissions. To simplify computations, it has been assumed that only 10- and 12-inch joists would be sold, and that their sales ratio would be 1 lineal foot of 10-inch for each 2 lineal feet of 12-inch (table 9-1).

Distribution Methods

Of the various products from the proposed plant (table 9-1), the fabricated joists present the most difficult marketing problem. A sawmill in the Rocky Mountain Region manufacturing perhaps 40 million bd ft annually of a known product such as kiln-dry #2 and better random-length Douglas-fir and larch 2 by 10's and 2 by 12's, could expect to market such lumber through established wholesale networks. A new product such as the fabricated joists (figs. 3-2 and 3-3), however, presents a significant marketing challenge.

To put the challenge in perspective, the annual output of fabricated joists shown in table 9-1 represents a shipping weight of about 28,085 tons, or about 432 65-ton carloads. The very largest distributors of competitive fabricated joists—all in the Northeast—each market about 50 carloads annually, and it has taken such distributing yards several years to attain this volume. This suggests that a network of at least 50, and perhaps as many as 200, distributing yards would be required to market the plant output.

Some yards would stock the joists in relatively short lengths—for example 16 to 24 feet. To make most effective use of the product, however, the joists should be shipped to the distributor in the maximum length practical for the proposed manufacturing plant, that is 64 feet. Two experienced operators working in unison on a pair of large forklifts require about 3 hours to unload a 65-ton unitized load of such long fabricated joists from a flatcar. A 64-foot length of the proposed 12-inch-deep joist will weigh about 198 pounds. The joists would be stored near trim saws and cut to length as specified by builders. Joists would mostly be trimmed to 28 feet or less. Short trim ends would be converted to blocking.

Supplying the joists through distribution yards would assure ready and prompt availability to builders. Rail cars may have to be ordered 6 to 8 weeks in advance of shipment and may be in transit an average of 14 days to the East Coast. Three technical sales representatives each making two calls per day could visit about 100 distributors three times annually. Sales and technical assistance calls probably should not fall below this frequency.

A large investment in time, energy, and money by the sales staff would be required in the 2 years before plant startup to get the distribution system in place so that the plant could come up to full production within the first 3 months of operation.

Because the joists will be produced under strict quality control and are designed to be significantly stiffer and stronger than major competitive joists (table 3-3)—although slightly heavier—and will be priced 10 percent below the price of the competitive joists, it would seem that joists produced by the proposed plant can be competitive.

9-6 ORIENTED-STRAND BOARD

Markets

The annual consumption of structural panels is increasing in both the United States and Canada, and is expected to further increase to the end of the century (figs. 9-5 and 9-6). In the United States, structural plywood consumption is forecast to increase moderately through 1990, but thereafter decrease (fig. 9-5). In Canada, however, structural plywood consumption is decreasing and will likely continue to decrease (fig. 9-6). In both countries the consumption of waferboard/OSB structural panels is forecast to increase through the year 2000. Study of the consumption of all of the major panel products in North America reveals an almost explosive growth in demand for waferboard/OSB (fig. 9-7). From 1996 through 2000, annual consumption of waferboard/OSB is forecast to be about 15 billion ft^2, $^3/_8$-inch basis (fig. 9-5).

As noted previously, this trend is driven by higher timber prices and increasing price but diminishing quality of solid-wood products. Countervailing these influences, however, is the increasing price of phenol formaldehyde resins. For example, the cost of resin in a thousand square feet of $^7/_{16}$-inch OSB rose from about $15 in 1986 to about $17 by the end of 1987.

In 1984, installed plant annual capacity for OSB/waferboard in the United States was about 3.4 billion ft^2, $^3/_8$-inch basis (table 9-2). Additionally, Canadian capacity totaled about 1.6 billion ft^2 (table 9-3). (An updating by the Forest Products Laboratory, Madison, WI, the end of 1987; suggests that current capacity is near double that tabulated for 1984.)

Readers interested in a brief account of the inception of the structural flakeboard industry (waferboard and OSB) are referred to Koch and Springate (1983).

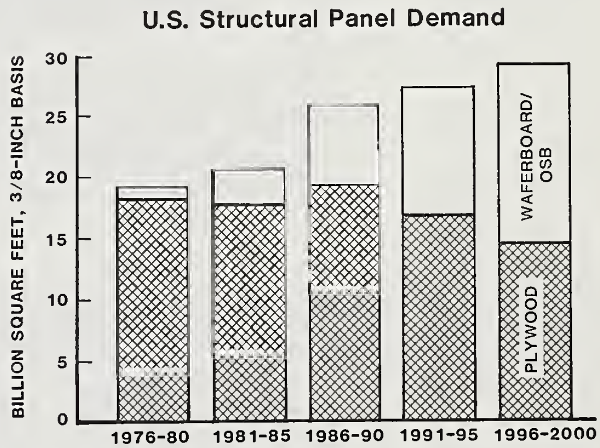

Figure 9-5—Annual demand for OSB/waferboard and plywood structural panels in the United States since 1976, with projections to the year 2000. Data from Bernard E. Fuller, Resource Information Systems, Bedford, MA (March 25, 1987).

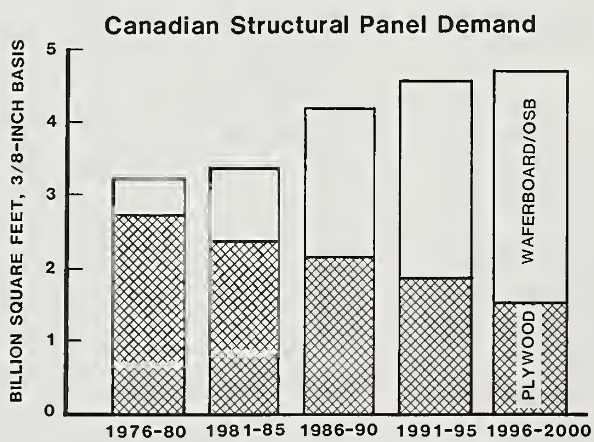

Figure 9-6—Annual demand for OSB/waferboard and plywood structural panels in Canada since 1976, with projections to the year 2000. Data from Bernard E. Fuller, Resource Information Systems, Bedford, MA (March 25, 1987).

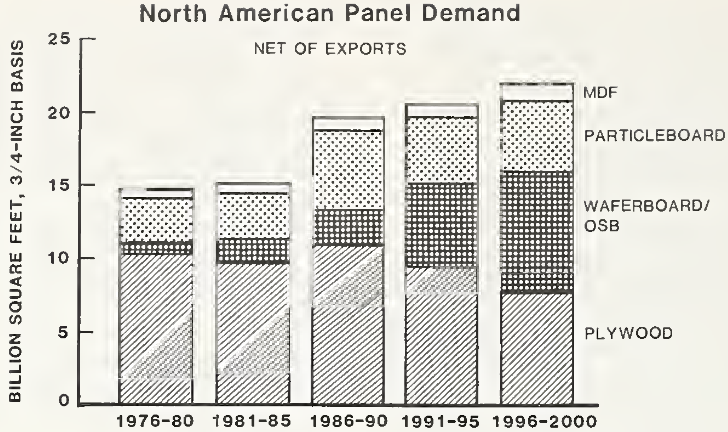

Figure 9-7—North American annual demand for panels of medium-density fiberboard (MDF), particleboard, OSB/ waferboard, and plywood since 1976, with projections to the year 2000. Data from Bernard E. Fuller, Resource Information Systems, Bedford, MA (March 25,1987).

Table 9-2—Data on plants producing waferboard (W) and oriented strand board (OSB) in the United States (from information compiled in 1988 by R. Geimer, Forest Products Laboratory, USDA Forest Service)

Company	Species	Wood used per year	Annual volume of plant	Press size	Press openings	Date of startup	Product
		Cords	*Million ft³ ³/₈-inch*	*Feet*	*No.*	*Year*	
Arrowood Technologies Roxboro, NC	Yellow poplar	[1]—	130	—	—	1987	Comply structural lumber (veneer over OSB)
Blandin Wood Products Grand Rapids, MI	Aspen	200,000	285	8x28	12	1972	W; 4-layer ¹/₄-³/₄; sheathing; T&G[2]; cut stock
Georgia Pacific Corp. Woodland, ME	35% spruce 35% fir 30% mixed softwoods	120,000	170	8x16	16	1980	W; 4-layer ¹/₄-³/₄; decorative panels; sheathing; T&G
Georgia Pacific Corp. Dudley, NC	Southern pine	—	220	—	—	1987	OSB
Georgia Pacific Corp. Emporia, VA	—	—	—	—	—	Planned	OSB
Georgia Pacific Corp. Glade Spring, VA	—	—	200	—	—	Planned	OSB
Georgia Pacific Corp. Grenada, MS	—	—	250	—	—	1987	OSB
International Paper Co. Nacogdoches, TX	—	—	200	—	—	1987	OSB
J.M. Huber Corp. Easton, ME	Aspen	112,000	160	8x16	12	1983	OSB; 3-layer ¹/₄-³/₄; sheathing; T&G
Louisiana-Pacific Corp. Corrigan, TX	Southern pine	—	150	4x25	14	1983	OSB; 3-layer ¹/₄-⁵/₈; 3-layer sheathing; flooring
Louisiana-Pacific Corp. Hayward, WI	Aspen	274,000	350	8x16 8x16	12 12	1979 1982	OSB; 3-layer ¹/₄-³/₄; sheathing; embossed lap siding and modular panels

(con.)

Table 9-2 (Con.)

Company	Species	Wood used per year	Annual volume of plant	Press size	Press openings	Date of startup	Product
		Cords	Million ft^3 $^3/_8$-inch	Feet	No.	Year	
Louisiana-Pacific Corp. Houlton, ME	Aspen	137,000	175	8x16	12	1981	OSB; 3-layer $^1/_4$-$^3/_4$
Louisiana-Pacific Corp. Kremmling, CO	Aspen & lodgepole pine	60,000	100	8x16	8	1984	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing
Louisiana-Pacific Corp. Montrose, CO	Aspen	60,000	125	8x16	8	1984	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing; T&G
Louisiana-Pacific Corp. Athol, ID	Lodgepole pine	75,000	90+	8x16	8	1984	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing
Louisiana-Pacific Corp. Logansport, LA	—	—	—	—	—	Planned	OSB
Louisiana-Pacific Corp. Grenada, MS	—	—	75			Planned	OSB
Louisiana-Pacific Corp. Urania, LA	—	—	150	—	—	1987	OSB
Louisiana-Pacific Corp. Dungannon, VA	Yellow poplar	—	100	—	—	1986	OSB
Louisiana-Pacific Corp. Two Harbors, ME	Aspen	—	100	8x16	8	1985	OSB; 3-layer, sheathing; paper-overlay siding
Louisiana-Pacific Corp. Jackson Co., GA	—	—	250	—	—	—	OSB
Louisiana-Pacific Corp. Sagola, MI	—	—	260	—	—	—	OSB
Louisiana-Pacific Corp. New Waverly, TX	—	—	100	—	—	—	OSB
Martco Lemoyen, LA	60 percent sweetgum and oak; 40 percent other hardwoods	84,000	170	8x16	16	1983	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing
Northwood Bemidji, MN	Aspen	200,000	240	8x24	14	1981	OSB; 4-layer $^1/_4$-$^3/_4$; T&G; grooved wall panels
Potlatch Corp. Bemidji, MN	Aspen	—	180 to 450	4x24	22	1981 1985	OSB; 5-layer; sheathing
Potlatch Corp. Cook, MN	Aspen	150,000	170	4x24	22	1983	OSB; 5-layer $^3/_8$-$^3/_4$; sheathing; flooring
Temple-Eastex, Inc. Claremont, NH	White pine and aspen	65,000	110	4x16	16	1981	OSB; 3-layer $^7/_{16}$-$^3/_4$; sheathing; flooring
Weyerhaeuser Co. Grayling, MI	Aspen plus some jack pine and mixed hardwoods	290,000	300	8x24	16	1982	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing; flooring
Weyerhaeuser Co. Elkin, NC	—	—	200	—	—	1987	OSB

[1]—means missing data.
[2]Tongue and groove panels.

Table 9-3—Data on plants producing oriented strand board or waferboard in Canada (from information compiled in 1988 by R. Geimer, Forest Products Laboratory, USDA Forest Service)

Company	Annual volume of plant	Press size	Press openings	Date of startup
	Million ft³ ³/8-inch	*Feet*	*No.*	*Year*
Forex Val d'Or, PQ	140	8x16	12	1982
Grant Lumber Englehart, ON	160	8x16	14	1981
Great Lakes Thunder Bay, ON	110	8x20	10	1976
Louisiana-Pacific Corp. Dawson Creek, BC	240	8x24	12	1988
Malette Timmons, ON	60	8x16	6	1973
Malette St. Georges, PQ	130	8x16	12	1981
MacMillan Bloedel Thunder Bay, ON	135	4x24	16	[1]—
MacMillan Bloedel Hudson Bay, SK	180	4x16 4x16	14 18	1969
Normick Perron La Sarre, PQ	60	8x16	6	1980
Northwood Chatham, NB	160	8x24	11	1979
Pelican Mills Drayton Valley, AB	240	8x24	12	1987
Pelican Mills Edson, AB	240	8x24	12	1983
Weldwood Longlac, ON	135	4x16	24	1974
Weldwood Slave Lake, AB	135	4x16	24	—

[1]—means missing data.

Product Selling Prices

The principal OSB commodity produced by the proposed plant will be 7/16-inch-thick sheathing panels. Price history on this product is limited to recent years because it is a new commodity. For the 5-year period 1982 through 1986, the price of 7/16-inch-thick sheathing averaged about $155/M ft² delivered Chicago (1982 and 1983), or net f.o.b. North Central mill (fig. 9-8). During 1984, 1985, and 1986, tongued-and-grooved panels 3/4-inch thick for decking averaged $280/M ft² net f.o.b. North Central mill (fig. 9-9), offering a slightly higher revenue per ton of product compared to 7/16-inch sheathing, but requiring one additional operation to manufacture.

With significant new manufacturing capacity coming onstream each recent year, prices for OSB have not been buoyant, but neither have they been consistently depressed (fig. 9-8)—although in November (typically a month of low demand) 1987, the price of 7/16-inch sheathing was at a low of $131/M ft² f.o.b. North Central mill. North Central mills have significantly less freight cost to reach important Midwest and Eastern markets than the proposed mill in northwestern Montana.

For the purposes of this analysis, 7/16-inch OSB sheathing is priced at $130/M ft², net f.o.b. mill after all discounts and commissions.

Distribution Methods

It is contemplated that 80 to 90 percent of the plant output of OSB will be marketed through a long-term (5 to 7 years) sales agreement with a major producer and distributor of forest products—one with a network of distribution warehouses. Such agreements typically guarantee sales of the commodity as it is produced—at market price.

The balance of the output will be sold by inhouse salespersons.

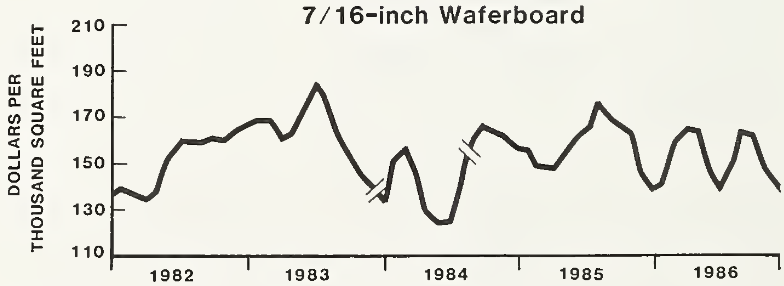

Figure 9-8—Five-year price trend for 7/16-inch-thick waferboard (including OSB). Prices prior to 1984 delivered Chicago; prices thereafter are net f.o.b. North Central mill. Data from Random Lengths (Richards 1987).

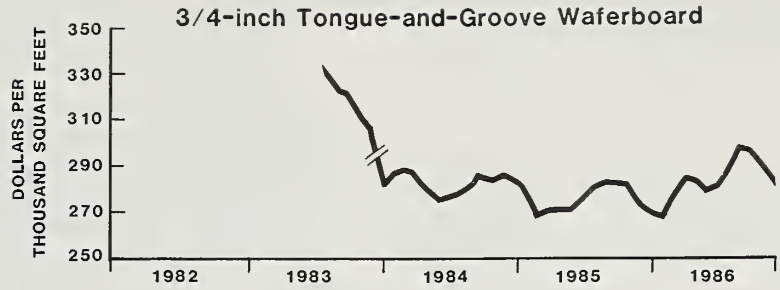

Figure 9-9—Price trend for 3.5 years for $^3/_4$-inch tongue-and-groove waferboard (including OSB). Prices prior to 1984 delivered Chicago; prices thereafter are net f.o.b. North Central mill. Data from Random Lengths (Richards 1987).

9-7 ORIENTED-STRAND LUMBER

As mentioned in section 4-5, the plant will be arranged to permit manufacture of 32-foot-long, 1.5-inch-thick oriented-strand lumber. Because the technical problems of manufacture and the likely properties of such lumber are as yet undetermined, it is premature to define markets, price, and distribution methods. Obviously, manufacture of oriented-strand lumber would be undertaken only if the obtainable price per ton favored such production over sheathing or decking.

9-8 PULP CHIPS

Production of pulp chips will be modest (table 9-1), and it is assumed the entire output will be sold to a pulp mill near Missoula, MT, at $22 per unit weighing 2,400 pounds ovendry. This price corresponds to $18.33/ton, ovendry basis, net f.o.b. the Libby-Troy plant. The price was developed based on information obtained from sawmill operators currently selling chips in Montana and northern Idaho.

9-9 PARTICLEBOARD FURNISH

It is assumed that planer shavings and other material suitable for particleboard furnish and excess to plant fuel needs will be sold to the large particleboard plant in Missoula. Return on wood sold for this purpose is nominal. To be conservative, a price of $1/ton, ovendry-weight basis, net f.o.b. the Libby-Troy plant, loaded in cars or trucks, is used in this feasibility analysis.

9-10 REFERENCES

Koch, Peter; Springate, Norman C. 1983. Hardwood structural flakeboard—development of the industry in North America. Journal of Forestry. 81(3): 160-161.

Richards, Terri L., ed. 1987. Random lengths 1986 yearbook. Vol. 22. Eugene, OR: Random Lengths Publications, Inc. 202 p.

CHAPTER 10: CASH-FLOW ANALYSIS AND RETURN ON INVESTMENT

CONTENTS

10-1 INTRODUCTION

As outlined in previous chapters, we believe that the processes described for the proposed integrated plant are technically feasible. We also believe that the Libby-Troy procurement area at this time offers sufficient sub-sawlog-size, marginal sawlog-size, and dead lodgepole pine timber—together with trees of associated species of less than sawlog quality, to support the proposed plant.

Chapter 7 estimates operating costs and capital requirement, and delineates business assumptions related to economic analysis of the proposed enterprise.

This final chapter estimates the return on investment from this integrated multiproduct facility.

As previously noted (fig. 3-8), the facility is designed to annually process 200,000 tons of stemwood (ovendry-weight basis) from currently unmerchantable trees—mostly lodgepole pines 3 to 7 inches in d.b.h. Several manufacturing centers (fig. 5-2) will be integrated to produce the following products:

- market OSB (oriented-strand board)
- fabricated joists
- edge-glued lumber panels
- studs
- tree props and fence rails
- pulp chips
- particleboard furnish

The products are described in chapter 3 and in appendix III. The projected sales volume of each is shown in table 9-1.

The facility will generate an estimated $40 million in revenue in its first year of full production (table 10-1), and will operate for 20 years. It will require $62 million in capital and have operating costs before depreciation of $30 million in the first year of full production. Estimates of capital requirements, operating costs, and revenues are discussed in chapters 6, 7, and 9, respectively.

10-2 CASH-FLOW: 50 PERCENT DEBT, 50 PERCENT EQUITY FINANCING

The financial analysis is based on the assumption that the project will be developed by a Fortune-500-type company, domestic or foreign, with a good credit rating and ready access to the financial markets. This was the basis of the financing arrangement outlined in chapter 7.

To summarize, a line of credit would be established to handle the construction activities and to provide working capital for the initial phases of plant operation. Long-term financing for the facility would consist of a $31 million bond issue at 10 percent interest, and a $31 million common stock issue. It was assumed that the construction loan and working capital credit line would be at 10 percent interest. Other costs associated with the issue of the bonds and stocks are discussed in chapter 7.

Projected after-tax cash-flows, based on 50 percent equity financing for the 20-year production period, are shown in table 10-1. Interest expense on the bond issue has been deducted from the total revenue to calculate taxable income, and bond principal repayment has been deducted from taxable income. The adjusted cash-flow, therefore, represents the cash-flow—after corporate income taxes—to equity investors.

This after-tax average annual return on the equity investment of $31 million is estimated at 25.1 percent over the 22-year life of the project (table 10-1).

Table 10-1—Cash-flow: 50 percent debt, 50 percent equity financing (totals and subtotals may not sum due to rounding)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenues								
Sales	$ 0	$ 0	$33,422,375	$39,915,865	$41,712,079	$43,589,122	$45,550,633	$47,600,411
Sale of assets								
Total revenues	0	0	33,422,375	39,915,865	41,712,079	43,589,122	45,550,633	47,600,411
Expenses								
Material costs	0	0	10,957,625	12,973,828	13,440,886	13,924,758	14,426,049	14,945,387
Labor costs	222,000	906,000	7,588,000	8,984,192	9,307,623	9,642,697	9,989,834	10,349,468
Supplies and services	0	0	806,006	1,670,045	1,730,167	1,792,453	1,856,981	1,923,832
Sales costs	0	437,500	875,000	906,500	939,134	972,943	1,007,969	1,044,256
Professional services & insurance	0	0	735,000	761,460	788,873	817,272	846,694	877,175
Property taxes	0	0	500,000	518,000	536,648	555,967	575,982	646,718
Utilities	0	0	1,491,000	1,544,676	1,600,284	1,657,895	1,717,579	1,779,412
Depreciation	0	0	6,574,461	11,064,608	7,994,325	5,809,117	4,244,176	4,252,889
Amortization	0	0	11,625	11,625	11,625	11,625	11,625	11,625
Interest	0	0	3,126,787	3,033,246	2,973,796	2,908,252	2,835,990	2,756,322
Total expenses	222,000	1,343,500	32,665,505	41,468,180	39,323,360	38,092,978	37,512,879	38,587,083
Taxable income (loss)	(222,000)	(1,343,500)	756,870	(1,552,315)	2,388,719	5,496,144	8,037,754	9,013,329
Adjustments to cash-flow								
Add: Stock sale	0	0	31,000,000	0	0	0	0	0
: Bond sale	0	0	31,000,000	0	0	0	0	0
: Construction loan draw	2,095,198	59,038,524	1,844,622	0	0	0	0	0
: Depreciation & amortization	0	0	6,586,086	11,076,233	8,005,950	5,820,742	4,255,801	4,264,514
Less: Construction costs & vehicles	(1,798,234)	(51,935,516)	0	0	0	0	0	(70,174)
: Bond principal payments	0	0	(526,077)	(580,000)	(639,450)	(704,994)	(777,256)	(856,924)
: Increase in accounts receivable	0	0	(3,183,083)	(143,239)	(149,684)	(156,420)	(163,459)	(170,815)
: Increase in log inventory	0	(1,374,646)	(1,756,104)	(112,707)	(116,764)	(120,968)	(125,323)	(129,834)
: Stock and bond issue expenses	0	(1,662,500)	0	0	0	0	0	0
: Construction loan payment	0	0	(62,978,343)	0	0	0	0	0
: Construction loan interest	(74,964)	(2,722,361)	0	0	0	0	0	0
Pretax cash-flow	0	0	2,743,970	8,687,972	9,488,770	10,334,504	11,227,517	12,050,095
Tax benefit (detriment)	90,465	547,476	(308,425)	632,568	(973,403)	(2,239,679)	(3,275,385)	(3,672,931)
After-tax cash-flow	90,465	547,476	2,435,546	9,320,541	8,515,367	8,094,825	7,952,132	8,377,164

(con.)

Table 10-1 (Con.)

	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16
Revenues								
Sales	$49,742,430	$51,980,839	$54,319,977	$56,764,376	$59,318,773	$61,988,118	$64,777,583	$67,692,574
Sale of assets								
Total revenues	49,742,430	51,980,839	54,319,977	56,764,376	59,318,773	61,988,118	64,777,583	67,692,574
Expenses								
Material costs	15,483,421	16,040,824	16,618,293	17,216,552	17,836,348	18,478,456	19,143,681	19,832,853
Labor costs	10,722,049	11,108,043	11,507,933	11,922,218	12,351,418	12,796,069	13,256,728	13,733,970
Supplies and services	1,993,090	2,064,841	2,139,176	2,216,186	2,295,969	2,378,624	2,464,254	2,552,967
Sales costs	1,081,849	1,120,795	1,161,144	1,202,945	1,246,251	1,291,116	1,337,596	1,385,750
Professional services & insurance	908,753	941,468	975,361	1,010,474	1,046,851	1,084,538	1,123,581	1,164,030
Property taxes	719,999	795,919	874,572	956,057	990,475	1,026,132	1,063,073	1,101,344
Utilities	1,843,470	1,909,835	1,978,589	2,049,819	2,123,612	2,200,062	2,279,264	2,361,318
Depreciation	4,257,007	2,301,083	348,752	348,752	361,460	367,468	356,748	350,316
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	11,625	11,625
Interest	2,668,487	2,571,649	2,464,886	2,347,179	2,217,407	2,074,333	1,916,595	1,742,688
Total expenses	39,689,751	38,866,084	38,080,331	39,281,807	40,481,416	41,708,423	42,953,145	44,236,861
Taxable income (loss)	10,052,679	13,114,755	16,239,646	17,482,569	18,837,357	20,279,695	21,824,438	23,455,714
Adjustments to cash-flow								
Add: Stock sale	0	0	0	0	0	0	0	0
: Bond sale	0	0	0	0	0	0	0	0
: Construction loan draw	0	0	0	0	0	0	0	0
: Depreciation & amortization	4,268,632	2,312,708	360,377	360,377	373,085	379,093	368,373	361,941
Less: Construction costs & vehicles	0	0	0	0	(83,748)	0	0	0
: Bond principal payments	(944,759)	(1,041,597)	(1,148,360)	(1,266,067)	(1,395,839)	(1,538,913)	(1,696,651)	(1,870,558)
: Increase in accounts receivable	(178,502)	(186,534)	(194,928)	(203,700)	(212,866)	(222,445)	(232,455)	(242,916)
: Increase in log inventory	(134,508)	(139,351)	(144,367)	(149,565)	(154,949)	(160,527)	(166,306)	(172,293)
: Stock and bond issue expenses	0	0	0	0	0	0	0	0
: Construction loan payment	0	0	0	0	0	0	0	0
: Construction loan interest	0	0	0	0	0	0	0	0
Pretax cash-flow	13,063,542	14,059,982	15,112,367	16,223,614	17,363,039	18,736,902	20,097,398	21,531,888
Tax benefit (detriment)	(4,096,467)	(5,344,263)	(6,617,656)	(7,124,147)	(7,676,223)	(8,263,976)	(8,893,459)	(9,558,203)
After-tax cash-flow	8,967,075	8,715,719	8,494,711	9,099,467	9,686,816	10,472,926	11,203,940	11,973,684

(con.)

Table 10-1 (Con.)

	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Sale
Revenues							
Sales	$70,738,740	$73,921,983	$77,248,473	$80,724,654	$84,357,263	$88,153,340	$ 0
Sale of assets							374,928
Total revenues	70,738,740	73,921,983	77,248,473	80,724,654	84,357,263	88,153,340	374,928
Expenses							
Material costs	20,546,836	21,286,522	22,052,837	22,846,739	23,669,222	24,521,314	0
Labor costs	14,228,393	14,740,615	15,271,277	15,821,043	16,390,601	16,980,662	0
Supplies and services	2,644,874	2,740,089	2,838,733	2,940,927	3,046,800	3,156,485	0
Sales costs	1,435,637	1,487,320	1,540,863	1,596,334	1,653,803	1,713,339	0
Professional services & insurance	1,205,935	1,249,349	1,294,325	1,340,921	1,389,194	1,439,205	0
Property taxes	1,140,992	1,182,068	1,224,622	1,268,708	1,314,382	1,361,700	0
Utilities	2,446,325	2,534,393	2,625,631	2,720,154	2,818,080	2,919,530	0
Depreciation	350,316	357,235	356,159	343,366	335,690	335,690	3,919,489
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	0
Interest	1,550,956	1,339,571	1,106,519	849,580	56,304	253,992	0
Total expenses	45,561,889	46,928,787	48,322,592	49,739,398	51,195,699	52,693,543	3,919,489
Taxable income (loss)	25,176,851	26,993,196	28,925,881	30,985,256	33,161,564	35,459,797	(3,544,561)
Adjustments to cash-flow							
Add: Stock sale	0	0	0	0	0	0	0
: Bond sale	0	0	0	0	0	0	0
: Construction loan draw	0	0	0	0	0	0	0
: Depreciation & amortization	361,941	368,860	367,784	354,991	347,315	347,315	3,919,489
Less: Construction costs & vehicles	0	0	0	(99,948)	0	0	0
: Bond principal payments	(2,062,290)	(2,273,675)	(2,506,727)	(2,763,666)	(3,046,942)	(3,359,254)	0
: Increase in accounts receivable	(253,847)	(265,270)	(277,207)	(289,682)	(302,717)	(316,340)	7,346,112
: Increase in log inventory	(178,496)	(184,922)	(191,579)	(198,476)	(205,621)	(213,023)	0
: Stock and bond issue expenses	0	0	0	0	0	0	0
: Construction loan payment	0	0	0	0	0	0	0
: Construction loan interest	0	0	0	0	0	0	0
Pretax cash-flow	23,044,159	24,638,190	26,318,152	27,988,476	29,953,599	31,918,496	7,721,040
Tax benefit (detriment)	(10,259,567)	(10,999,727)	(11,787,296)	(12,626,492)	(13,513,337)	(14,449,867)	1,444,409
After-tax cash-flow	12,784,592	13,638,462	14,530,856	15,361,984	16,440,261	17,468,628	9,165,448

10-3 CASH-FLOW: EXCLUDING FINANCING FLOWS

Because the return on investment varies as the project's financing varies, an additional analysis was performed using the traditional approach to capital budgeting as described by Brigham (1979). This method does not explicitly bring the project's financing into the cash-flow analysis. The traditional financial model employed can be simply described as:

Net cash-flow = net income + depreciation

An adjustment to cash-flow was also made in this traditional analysis to show prepayment of raw materials inventory and to carry accounts receivable.

Under the assumptions described here and in earlier chapters, the net cash-flows using the traditional model show a 16.8 percent average annual rate of return from the project after corporate income taxes over the project's 22-year life. The traditional method is displayed (table 10-2) primarily because it is the method commonly used internally by business firms.

As illustrated in the discussion of 50 percent debt financing (section 10-2), return to the equity investors can exceed the traditional method's return by a substantial amount if a sizable proportion of debt financing is used.

10-4 REFERENCE

Brigham, Eugene F. 1979. Financial management: theory and practice. 2d ed. Hinsdale, IL: The Dryden Press: chapter 11.

Table 10-2—Cash-flow: excluding financing flows (totals and subtotals may not sum due to rounding)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenues								
Sales	$ 0	$ 0	$33,422,375	$39,915,865	$41,712,079	$43,589,122	$45,550,633	$47,600,411
Sale of assets								
Total revenues	0	0	33,422,375	39,915,865	41,712,079	43,589,122	45,550,633	47,600,411
Expenses								
Material costs	0	0	10,957,625	12,973,828	13,440,886	13,924,758	14,426,049	14,945,387
Labor costs	222,000	906,000	7,588,000	8,984,192	9,307,623	9,642,697	9,989,834	10,349,468
Supplies and services	0	0	806,006	1,670,045	1,730,167	1,792,453	1,856,981	1,923,832
Sales costs	0	437,500	875,000	906,500	939,134	972,943	1,007,969	1,044,256
Professional services & insurance	0	0	735,000	761,460	788,873	817,272	846,694	877,175
Property taxes	0	0	500,000	518,000	536,648	555,967	575,982	646,718
Utilities	0	0	1,491,000	1,544,676	1,600,284	1,657,895	1,717,579	1,779,412
Depreciation	0	0	6,574,461	11,064,608	7,994,325	5,809,117	4,244,176	4,252,889
Amortization	0	0	11,625	11,625	11,625	11,625	11,625	11,625
Total expenses	222,000	1,343,500	29,538,718	38,434,934	36,349,564	35,184,726	34,676,888	35,830,761
Taxable income (loss)	(222,000)	(1,343,500)	3,883,657	1,480,931	5,362,515	8,404,397	10,873,745	11,769,650
Adjustments to cash-flow								
Add: Depreciation & amortization	0	0	6,586,086	11,076,233	8,005,950	5,820,742	4,255,801	4,264,514
Less: Construction costs & vehicles	(1,798,234)	(51,935,516)	0	0	0	0	0	(70,174)
: Increase in accounts receivable	0	0	(3,183,083)	(143,239)	(149,684)	(156,420)	(163,459)	(170,815)
: Increase in log inventory	0	(1,374,646)	(1,756,104)	(112,707)	(116,764)	(120,968)	(125,323)	(129,834)
Pretax cash-flow	(2,020,234)	(54,653,662)	5,530,556	12,301,218	13,102,016	13,947,750	14,840,763	15,663,341
Tax benefit (detriment)	90,465	547,476	(1,582,590)	(603,479)	(2,185,225)	(3,424,792)	(4,431,051)	(4,796,132)
After-tax cash-flow	(1,929,769)	(54,106,186)	3,947,966	11,697,739	10,916,791	10,522,958	10,409,712	10,867,209

(con.)

Table 10-2 (Con.)

	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16
Revenues								
Sales	$49,742,430	$51,980,839	$54,319,977	$56,764,376	$59,318,773	$61,988,118	$64,777,583	$67,692,574
Sale of assets								
Total revenues	49,742,430	51,980,839	54,319,977	56,764,376	59,318,773	61,988,118	64,777,583	67,692,574
Expenses								
Material costs	15,483,421	16,040,824	16,618,293	17,216,552	17,836,348	18,478,456	19,143,681	19,832,853
Labor costs	10,722,049	11,108,043	11,507,933	11,922,218	12,351,418	12,796,069	13,256,728	13,733,970
Supplies and services	1,993,090	2,064,841	2,139,176	2,216,186	2,295,969	2,378,624	2,464,254	2,552,967
Sales costs	1,081,849	1,120,795	1,161,144	1,202,945	1,246,251	1,291,116	1,337,596	1,385,750
Professional services & insurance	908,753	941,468	975,361	1,010,474	1,046,851	1,084,538	1,123,581	1,164,030
Property taxes	719,999	795,919	874,572	956,057	990,475	1,026,132	1,063,073	1,101,344
Utilities	1,843,470	1,909,835	1,978,589	2,049,819	2,123,612	2,200,062	2,279,264	2,361,318
Depreciation	4,257,007	2,301,083	348,752	348,752	361,460	367,468	356,748	350,316
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	11,625	11,625
Total expenses	37,021,264	36,294,435	35,615,446	36,934,628	38,264,009	39,634,090	41,036,550	42,494,173
Taxable income (loss)	12,721,166	15,686,405	18,704,531	19,829,748	21,054,764	22,354,028	23,741,033	25,198,402
Adjustments to cash-flow								
Add: Depreciation & amortization	4,268,632	2,312,708	360,377	360,377	373,085	379,093	368,373	361,941
Less: Construction costs & vehicles	0	0	0	0	(83,748)	0	0	0
: Increase in accounts receivable	(178,502)	(186,534)	(194,928)	(203,700)	(212,866)	(222,445)	(232,455)	(242,916)
: Increase in log inventory	(134,508)	(139,351)	(144,367)	(149,565)	(154,949)	(160,527)	(166,306)	(172,293)
Pretax cash-flow	16,676,788	17,673,228	18,725,613	19,836,860	20,976,285	22,350,148	23,710,644	25,145,134
Tax benefit (detriment)	(5,183,875)	(6,392,210)	(7,622,096)	(8,080,622)	(8,579,816)	(9,109,266)	(9,674,471)	(10,268,349)
After-tax cash-flow	11,492,913	11,281,018	11,103,516	11,756,238	12,396,469	13,240,881	14,036,173	14,876,785

(con.)

Table 10-2 (Con.)

	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Sale
Revenues							
Sales	$70,738,740	$73,921,983	$77,248,473	$80,724,654	$84,357,263	$88,153,340	$ 0
Sale of assets							374,928
Total revenues	70,738,740	73,921,983	77,248,473	80,724,654	84,357,263	88,153,340	374,928
Expenses							
Material costs	20,546,836	21,286,522	22,052,837	22,846,739	23,669,222	24,521,314	0
Labor costs	14,228,393	14,740,615	15,271,277	15,821,043	16,390,601	16,980,662	0
Supplies and services	2,644,874	2,740,089	2,838,733	2,940,927	3,046,800	3,156,485	0
Sales costs	1,435,637	1,487,320	1,540,863	1,596,334	1,653,803	1,713,339	0
Professional services & insurance	1,205,935	1,249,349	1,294,325	1,340,921	1,389,194	1,439,205	0
Property taxes	1,140,992	1,182,068	1,224,622	1,268,708	1,314,382	1,361,700	0
Utilities	2,446,325	2,534,393	2,625,631	2,720,154	2,818,080	2,919,530	0
Depreciation	350,316	357,235	356,159	343,366	335,690	335,690	3,919,489
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	0
Total expenses	44,010,933	45,589,216	47,216,073	48,889,818	50,629,396	52,439,550	3,919,489
Taxable income (loss)	26,727,807	28,332,767	30,032,400	31,834,836	33,727,868	35,713,790	(3,544,561)
Adjustments to cash-flow							
Add: Depreciation & amortization	361,941	368,860	367,784	354,991	347,315	347,315	3,919,489
Less: Construction costs & vehicles	0	0	0	(99,948)	0	0	0
: Increase in accounts receivable	(253,847)	(265,270)	(277,207)	(289,682)	(302,717)	(316,340)	7,346,112
: Increase in log inventory	(178,496)	(184,922)	(191,579)	(198,476)	(205,621)	(213,023)	0
Pretax cash-flow	26,657,405	28,251,436	29,931,398	31,601,722	33,566,845	35,531,742	7,721,040
Tax benefit (detriment)	(10,891,581)	(11,545,603)	(12,238,203)	(12,972,696)	(13,744,106)	(14,553,369)	(1,444,409)
After-tax cash-flow	15,765,824	16,705,833	17,693,195	18,629,026	19,822,738	20,978,373	9,165,448

APPENDIX I: NUMBERS OF LIVE LODGEPOLE PINE TREES AND GROWING STOCK VOLUME ON COMMERCIAL TIMBER LAND IN 21 WESTERN MONTANA COUNTIES, BY TREE DIAMETER CLASS AND OWNERSHIP

Growing stock volume is cubic feet of stemwood in live lodgepole pine trees 5 inches in d.b.h. and larger from a 1-foot-high stump to a 4-inch top diameter measured outside bark. Data, based on survey information collected from 1966 to 1980, are from a special tabulation compiled by the Forest Survey Research Unit, Intermountain Research Station, USDA Forest Service, Ogden, UT.

From stump top to apical tip, typical stemwood volume of a lodgepole pine 2 inches in d.b.h. is about 1/3 ft^3; that of a 4-inch tree to apical tip is about 1 1/4 ft^3.

Diameter classes (measured at breast height, outside bark) span 1.9 inches; for example, the 4-inch class spans from 3.0 to 4.9 inches.

Table I-1—Number of trees and growing stock volume

Diameter class	Number of trees			Growing stock volume ft^3		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Beaverhead County, MT			
2	7,674,556	60,938,115	68,612,671	—	—	—
4	4,756,398	73,350,340	78,106,738	—	—	—
6	2,534,448	65,423,370	67,957,818	11,118,582	183,583,104	194,701,686
8	1,256,671	38,132,698	39,389,369	10,362,396	282,837,459	293,199,855
10	713,999	16,342,998	17,056,997	9,618,581	207,105,451	216,724,032
12	368,023	6,422,772	6,790,795	7,585,974	122,219,620	129,805,594
14	134,439	2,579,652	2,714,091	3,951,933	70,364,320	74,316,253
16	82,505	460,733	543,238	3,256,227	17,006,950	20,263,177
18	23,598	136,444	160,042	1,043,886	6,472,936	7,516,822
20	7,102	30,431	37,533	400,860	1,563,298	1,964,158
22	2,362	12,972	15,334	166,371	652,502	818,873
24	0	31,702	31,702	0	2,429,385	2,429,385
26	0	2,528	2,528	0	203,578	203,578
28	0	2,665	2,665	0	306,671	306,671
30+	0	4,732	4,732	0	777,133	777,133
Total	17,554,101	263,872,152	281,426,253	47,504,810	895,522,407	943,027,217
Inches			Broadwater County, MT			
2	2,771,971	3,750,842	6,522,813	—	—	—
4	597,491	5,583,298	6,180,789	—	—	—
6	417,872	7,203,789	7,621,661	1,661,991	19,688,993	21,350,984
8	259,987	4,683,299	4,943,286	1,898,541	33,770,479	35,669,020
10	64,433	2,171,715	2,236,148	750,111	27,228,963	27,979,074
12	33,084	912,121	945,205	478,326	15,968,847	16,447,173
14	10,182	286,785	296,967	222,952	7,021,399	7,244,351
16	3,341	106,539	109,880	92,787	3,457,019	3,549,806
18	719	37,653	38,372	37,311	1,545,865	1,583,176
20	691	8,707	9,398	40,592	448,998	489,590
22	0	7,060	7,060	0	444,442	444,442
24	0	0	0	0	0	0
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	4,159,771	24,751,808	28,911,579	5,182,611	109,575,005	114,757,616

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft³		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Carbon County, MT			
2	1,973,553	5,383,238	7,356,791	—	—	—
4	862,752	7,900,920	8,763,672	—	—	—
6	229,521	4,618,607	4,848,128	700,188	9,686,627	10,386,815
8	34,846	2,072,877	2,107,723	221,802	10,841,962	11,063,764
10	35,547	735,299	770,846	361,048	7,149,231	7,510,279
12	23,749	295,571	319,320	368,575	4,280,189	4,648,764
14	14,649	91,641	106,290	286,151	2,144,246	2,430,397
16	4,618	33,718	38,336	116,686	1,025,748	1,142,434
18	0	18,719	18,719	0	815,494	815,494
20	0	4,193	4,193	0	237,098	237,098
22	0	1,404	1,404	0	103,892	103,892
24	0	44	44	0	3,452	3,452
26	0	210	210	0	18,310	18,310
28	0	887	887	0	70,669	70,669
30+	0	0	0	0	0	0
Total	3,179,235	21,157,328	24,336,563	2,054,450	36,376,918	38,431,368
Inches			Deerlodge County, MT			
2	10,448,099	7,336,401	17,784,500	—	—	—
4	6,327,157	9,745,823	16,072,980	—	—	—
6	3,057,107	8,354,621	11,411,728	13,442,243	23,821,080	37,263,323
8	1,493,895	4,737,408	6,231,303	12,358,051	35,619,698	47,977,749
10	841,762	2,016,635	2,858,397	11,414,177	26,162,938	37,577,115
12	428,380	732,358	1,160,738	8,861,101	14,209,647	23,070,748
14	156,269	261,714	417,983	4,607,301	7,157,410	11,764,711
16	98,312	51,045	149,357	3,867,640	1,860,445	5,728,085
18	28,182	12,343	40,525	1,241,540	579,999	1,821,539
20	8,427	4,121	12,548	474,494	228,430	702,924
22	2,701	1,408	4,109	190,241	70,851	261,092
24	0	2,626	2,626	0	205,890	205,890
26	0	284	284	0	24,412	24,412
28	0	123	123	0	14,191	14,191
30+	0	422	422	0	69,576	69,576
Total	22,890,291	33,257,332	56,147,623	56,456,788	110,024,567	166,481,355
Inches			Flathead County, MT			
2	33,126,047	35,721,959	68,848,006	—	—	—
4	34,974,566	52,731,730	87,706,296	—	—	—
6	17,529,502	34,475,806	52,005,308	86,386,743	95,401,804	181,788,547
8	7,997,966	18,455,405	26,453,371	72,196,886	150,105,600	222,302,486
10	3,260,056	7,031,519	10,291,575	49,226,542	99,527,189	148,753,731
12	1,011,455	3,133,559	4,145,014	22,774,798	65,245,116	88,019,914
14	442,101	1,402,830	1,844,931	13,785,327	39,780,877	53,566,204
16	71,333	467,798	539,131	3,139,477	16,840,447	19,979,924
18	12,343	127,204	139,547	676,127	6,101,630	6,777,757
20	5,014	20,018	25,032	315,449	1,172,549	1,487,998
22	864	4,783	5,647	68,758	484,571	553,329
24	1,409	256	1,665	106,412	29,195	135,607
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	98,432,656	153,572,867	252,005,523	248,676,519	474,688,978	723,365,497

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft^3		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			**Gallatin County, MT**			
2	4,995,847	12,407,562	17,403,409	—	—	—
4	5,160,058	17,609,512	22,769,570	—	—	—
6	3,065,585	17,602,565	20,668,150	14,804,556	53,965,120	68,769,676
8	2,913,361	10,648,721	13,562,082	23,424,255	83,328,204	106,752,459
10	1,774,760	7,538,964	9,313,724	23,355,177	102,079,012	125,434,189
12	710,360	4,479,081	5,189,441	14,099,933	90,364,696	104,464,629
14	395,340	2,482,096	2,877,436	10,895,984	70,308,889	81,204,873
16	131,179	915,244	1,046,423	4,563,199	34,254,711	38,817,910
18	64,444	485,995	550,439	3,052,045	22,154,598	25,206,643
20	22,375	183,596	205,971	1,168,616	11,795,475	12,964,091
22	9,710	37,904	47,614	690,897	2,838,535	3,529,432
24	0	7,406	7,406	0	578,288	578,228
26	0	4,173	4,173	0	366,563	366,563
28	0	2,338	2,338	0	221,023	221,023
30+	0	0	0	0	39	39
Total	19,243,019	74,405,157	93,648,176	96,054,662	472,255,153	568,309,815
Inches			**Granite County, MT**			
2	17,520,886	25,404,217	42,925,103	—	—	—
4	8,449,153	45,508,604	53,957,757	—	—	—
6	4,416,579	42,727,634	47,144,213	21,303,581	131,448,248	152,751,829
8	2,502,814	24,056,373	26,559,187	21,981,755	194,221,172	216,202,927
10	899,567	10,025,809	10,925,376	13,206,729	141,091,320	154,298,049
12	302,775	3,519,475	3,822,250	6,372,288	74,193,442	80,565,730
14	121,701	980,450	1,102,151	3,636,188	28,568,582	32,204,770
16	29,306	277,782	307,088	1,029,887	10,783,123	11,813,010
18	16,974	52,152	69,126	740,794	2,479,469	3,220,263
20	3,613	29,376	32,989	182,292	1,841,035	2,023,327
22	651	2,331	2,982	46,906	182,913	229,819
24	1,386	1,252	2,638	93,428	142,562	235,990
26	1,043	866	1,909	71,536	96,891	168,427
28	0	0	0	0	0	0
30+	706	0	706	94,289	0	94,289
Total	34,267,154	152,586,321	186,853,475	68,759,673	585,048,757	653,808,430
Inches			**Jefferson County, MT**			
2	2,281,435	16,305,672	18,587,107	—	—	—
4	875,805	26,185,025	27,060,830	—	—	—
6	912,113	26,153,020	27,065,133	3,806,958	77,929,700	81,736,658
8	498,147	16,379,494	16,877,641	3,672,051	127,436,952	131,109,003
10	136,697	7,294,411	7,431,108	1,619,240	99,349,545	100,968,785
12	54,637	2,650,256	2,704,893	842,820	52,885,644	53,728,464
14	33,100	839,186	872,286	721,451	23,522,774	24,244,225
16	4,725	230,005	234,730	143,121	8,163,683	8,306,804
18	2,907	53,561	56,468	150,771	2,410,140	2,560,911
20	1,472	26,152	27,624	86,461	1,584,245	1,670,706
22	0	3,628	3,628	0	240,104	240,104
24	0	0	0	0	0	0
26	0	1,449	1,449	0	162,093	162,093
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	4,801,038	96,121,859	100,922,897	11,042,873	393,684,880	404,727,753

(con.)

Table I-1 (Con.)

Diameter class	Number of trees: State/ private	Number of trees: National Forest	Number of trees: Total	Growing stock volume ft³: State/ private	Growing stock volume ft³: National Forest	Growing stock volume ft³: Total
Inches			Lake County, MT			
2	2,251,115	3,651,931	5,903,046	—	—	—
4	2,410,093	5,393,586	7,803,679	—	—	—
6	2,564,199	3,473,752	6,037,951	12,885,735	9,359,817	22,245,552
8	1,610,891	1,861,561	3,472,452	14,625,369	15,292,448	29,917,817
10	561,115	743,517	1,304,632	8,114,254	10,746,200	18,860,454
12	260,635	337,860	598,495	5,774,142	7,122,908	12,897,050
14	75,085	163,612	238,697	2,373,831	4,776,416	7,150,247
16	22,300	50,390	72,690	877,901	1,820,727	2,698,628
18	4,409	14,114	18,523	215,381	662,480	877,861
20	4,971	1,560	6,531	331,005	94,027	425,032
22	2,783	351	3,134	212,324	37,347	249,671
24	0	1	1	0	101	101
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	9,767,596	15,692,235	25,459,831	45,409,942	49,912,471	95,322,413
Inches			Lewis and Clark County, MT			
2	16,316,841	25,093,045	41,409,886	—	—	—
4	6,195,210	35,694,353	41,889,563	—	—	—
6	4,383,421	37,594,940	41,978,361	19,563,774	103,984,920	123,548,694
8	2,510,012	22,138,337	24,648,349	20,124,699	162,295,504	182,420,203
10	814,329	9,466,319	10,280,648	11,001,231	119,690,731	130,691,962
12	300,185	3,992,264	4,292,449	5,542,057	71,209,738	76,751,795
14	137,094	1,200,232	1,337,326	3,517,154	29,967,980	33,485,134
16	27,545	411,724	439,269	916,200	13,819,864	14,736,064
18	12,973	147,461	160,434	620,691	6,093,971	6,714,662
20	6,654	32,569	39,223	375,480	1,739,820	2,115,300
22	214	19,851	20,065	15,421	1,347,760	1,363,181
24	513	307	820	34,600	18,923	53,523
26	251	199	450	17,220	17,645	34,865
28	0	0	0	0	0	0
30+	261	0	261	34,919	0	34,919
Total	30,705,503	135,791,601	166,497,104	61,763,446	510,186,856	571,950,302
Inches			Lincoln County, MT			
2	27,745,757	32,920,429	60,666,186	—	—	—
4	28,002,686	78,215,244	106,217,930	—	—	—
6	14,553,466	72,408,716	86,962,182	70,952,311	233,006,937	303,959,248
8	6,211,449	38,097,171	44,308,620	55,568,651	330,286,633	385,855,284
10	2,294,163	15,899,375	18,193,538	34,103,404	229,091,836	263,195,240
12	602,682	6,060,588	6,663,270	13,554,824	125,348,313	138,903,137
14	269,305	1,765,928	2,035,233	8,512,0135	46,975,408	55,487,421
16	48,443	523,057	571,500	2,179,469	21,265,463	23,444,932
18	11,328	149,023	160,351	619,923	8,588,889	9,208,812
20	3,109	64,104	67,213	195,601	4,354,396	4,549,997
22	943	15,732	16,675	75,075	1,002,952	1,078,027
24	432	0	432	32,653	0	32,653
26	0	0	0	0	0	0
28	0	10	10	0	1,944	1,944
30+	0	0	0	0	0	0
Total	79,743,763	246,119,377	325,863,140	185,793,924	999,922,771	1,185,716,695

(con.)

Table I-1 (Con.)

Diameter class	Number of trees: State/ private	National Forest	Total	Growing stock volume ft³: State/ private	National Forest	Total
Inches			Madison County, MT			
2	13,830,071	23,525,480	37,355,551	—	—	—
4	8,395,207	28,832,272	37,227,479	—	—	—
6	4,512,839	26,186,989	30,699,828	19,779,988	74,046,852	93,826,840
8	2,210,582	15,615,438	17,826,020	18,312,224	116,266,035	134,578,259
10	1,261,251	7,001,660	8,262,911	17,121,365	89,400,801	106,522,166
12	650,441	2,937,361	3,587,802	13,498,009	56,257,124	69,755,133
14	245,072	1,216,449	1,461,521	7,249,848	33,096,600	40,346,448
16	152,592	299,629	452,221	6,053,409	10,868,249	16,921,658
18	42,799	112,092	154,891	1,911,876	5,033,715	6,945,591
20	13,266	30,324	43,590	750,588	1,801,670	2,552,258
22	4,566	16,253	20,819	321,574	941,588	1,263,162
24	0	10,390	10,390	0	818,195	818,195
26	0	1,653	1,653	0	142,454	142,454
28	0	784	784	0	85,786	85,786
30+	0	1,578	1,578	0	259,187	259,187
Total	31,318,686	105,788,352	137,107,038	84,998,881	389,018,256	474,017,137
Inches			Meagher County, MT			
2	1,540,517	31,004,861	32,545,378	—	—	—
4	5,430,646	35,670,325	41,100,971	—	—	—
6	3,173,595	29,276,139	32,449,734	15,001,471	83,912,561	98,914,032
8	3,656,135	16,543,618	20,199,753	33,244,053	125,617,280	158,861,333
10	1,784,406	7,335,367	9,119,773	26,264,011	93,442,786	119,706,797
12	532,687	3,435,814	3,968,501	10,978,946	65,503,220	76,482,166
14	167,643	1,077,919	1,245,562	4,472,882	28,581,114	33,053,996
16	75,438	418,968	494,406	2,601,695	15,544,892	18,146,587
18	47,861	91,024	138,885	2,064,406	4,027,944	6,092,350
20	7,867	32,633	40,500	343,887	1,952,524	2,296,411
22	5,866	8,704	14,570	290,741	668,179	958,920
24	0	1,580	1,580	0	90,585	90,585
26	0	1,554	1,554	0	137,462	137,462
28	0	33	33	0	3,198	3,198
30+	0	0	0	0	0	0
Total	16,422,661	124,898,539	141,321,200	95,262,092	419,481,745	514,743,837
Inches			Mineral County, MT			
2	2,639,843	10,240,895	12,880,738	—	—	—
4	2,326,800	24,796,336	27,123,136	—	—	—
6	2,256,436	28,187,956	30,444,392	11,499,997	90,587,460	102,087,457
8	1,505,805	14,690,349	16,196,154	13,860,590	130,311,912	144,172,502
10	628,885	5,751,001	6,379,886	9,036,597	86,426,752	95,463,349
12	199,552	2,358,756	2,558,308	4,278,661	52,814,242	57,092,903
14	90,357	645,901	736,258	2,677,912	19,699,462	22,377,374
16	23,761	232,045	255,806	889,478	10,254,916	11,144,394
18	6,814	34,475	41,289	320,112	1,894,902	2,215,014
20	1,003	8,516	9,519	54,314	596,770	651,084
22	712	5,177	5,889	45,538	413,838	459,376
24	0	3,736	3,736	0	425,363	425,363
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	9,679,968	86,955,143	96,635,111	42,663,199	393,425,617	436,088,816

(con.)

Table I-1 (Con.)

Diameter class	Number of trees State/ private	National Forest	Total	Growing stock volume ft³ State/ private	National Forest	Total
Inches			Missoula County, MT			
2	19,857,177	9,311,080	29,168,257	—	—	—
4	16,314,967	19,885,125	36,200,092	—	—	—
6	14,287,634	21,688,208	35,975,842	71,866,144	68,810,402	140,676,546
8	8,630,893	11,431,454	20,062,347	80,286,020	100,948,786	181,234,806
10	3,390,307	4,599,047	7,989,354	49,184,547	68,977,193	118,161,740
12	1,010,971	1,883,688	2,894,659	21,534,106	42,263,739	63,797,845
14	470,845	570,619	1,041,464	13,773,568	17,276,608	31,050,176
16	110,834	208,906	319,740	3,991,533	9,024,412	13,015,945
18	32,221	34,022	66,243	1,484,016	1,818,232	3,302,248
20	5,815	8,271	14,086	314,985	578,307	893,292
22	3,447	4,752	8,199	220,364	382,673	603,037
24	0	2,316	2,316	0	263,689	263,689
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	64,115,111	69,627,488	133,742,599	242,655,283	310,344,041	552,999,324
Inches			Park County, MT			
2	2,830,273	10,189,267	13,019,540	—	—	—
4	2,352,599	13,747,994	16,100,593	—	—	—
6	1,897,103	14,302,980	16,200,083	9,405,821	43,672,366	53,078,187
8	1,803,390	9,466,621	11,270,011	14,586,837	74,323,062	88,909,899
10	1,116,156	7,869,776	8,985,932	14,984,302	106,495,348	121,479,650
12	504,498	4,922,229	5,426,727	9,986,625	99,144,744	109,131,369
14	278,397	2,791,703	3,070,100	7,887,462	79,585,256	87,472,718
16	85,419	1,017,836	1,103,255	3,018,863	38,617,044	41,635,907
18	52,266	549,198	601,464	2,397,909	25,287,823	27,685,732
20	18,696	209,842	228,538	988,856	13,313,142	14,301,998
22	7,269	40,295	47,564	509,998	3,034,924	3,544,922
24	0	9,368	9,368	0	731,329	731,329
26	0	6,674	6,674	0	585,143	585,143
28	0	3,020	3,020	0	284,545	284,545
30+	0	0	0	0	0	0
Total	10,946,066	65,126,803	76,072,869	63,766,673	485,074,726	548,841,399
Inches			Powell County, MT			
2	30,252,971	10,985,097	41,238,068	—	—	—
4	16,043,390	19,281,171	35,324,561	—	—	—
6	8,500,467	22,198,959	30,699,426	40,783,336	64,946,824	105,730,160
8	4,827,217	13,282,163	18,109,380	42,514,710	103,008,768	145,523,478
10	1,782,268	5,686,541	7,468,809	26,045,122	76,466,838	102,511,960
12	630,808	2,220,130	2,850,938	13,338,692	42,584,356	55,923,048
14	244,177	643,635	887,812	7,299,441	17,278,835	24,578,276
16	59,439	215,627	275,066	2,116,938	7,753,467	9,870,405
18	37,893	64,976	102,869	1,668,719	2,799,568	4,468,287
20	7,057	17,307	24,364	355,863	964,933	1,320,796
22	1,957	9,118	11,075	140,860	632,472	773,332
24	2,789	486	3,275	187,986	55,403	243,389
26	1,303	156	1,459	89,390	17,479	106,869
28	0	0	0	0	0	0
30+	1,420	0	1,420	189,719	0	189,719
Total	62,393,156	74,605,366	136,998,522	134,730,776	316,508,943	451,239,719

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft³		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Ravalli County, MT			
2	777,959	7,207,594	7,985,553	—	—	—
4	481,529	12,712,453	13,193,982	—	—	—
6	505,748	17,175,557	17,681,305	2,412,813	55,187,584	57,600,397
8	284,443	12,289,347	12,573,790	2,564,736	101,811,822	104,376,558
10	173,843	6,136,190	6,310,033	2,691,407	91,606,180	94,297,587
12	144,858	2,182,187	2,327,045	3,030,046	49,261,470	52,291,516
14	35,661	462,171	497,832	1,079,036	14,241,169	15,320,205
16	3,602	100,812	104,414	141,986	4,170,704	4,312,690
18	5,427	41,910	47,337	204,294	2,447,193	2,651,487
20	1,868	4,902	6,770	101,481	450,443	551,924
22	0	0	0	0	0	0
24	0	1,605	1,605	0	239,947	239,947
26	0	1,117	1,117	0	144,950	144,950
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	2,414,938	58,315,845	60,730,783	12,225,799	319,561,462	331,787,261
Inches			Sanders County, MT			
2	4,911,418	15,931,695	20,843,113	—	—	—
4	3,596,967	38,800,363	42,397,330	—	—	—
6	4,774,581	39,815,018	44,589,599	24,562,918	129,084,108	153,647,026
8	3,404,108	20,755,188	24,159,296	31,447,468	182,592,953	214,040,421
10	1,170,727	8,277,911	9,448,638	17,183,812	122,034,982	139,218,794
12	453,438	3,294,347	3,747,785	10,179,138	71,290,880	81,470,018
14	165,489	927,548	1,093,037	5,311,933	26,184,872	31,496,805
16	40,462	310,115	350,577	1,546,860	13,347,245	14,894,105
18	6,463	67,109	73,572	302,624	3,836,231	4,138,855
20	14,384	25,136	39,520	1,004,389	1,725,473	2,729,862
22	3,939	7,253	11,192	297,869	539,343	837,212
24	0	2,923	2,923	0	332,772	332,772
26	0	0	0	0	0	0
28	0	0	0	0	513	513
30+	0	0	0	0	0	0
Total	18,541,976	128,214,606	146,756,582	91,837,011	550,969,372	642,806,383
Inches			Silver Bow County, MT			
2	6,322,043	7,837,125	14,159,168	—	—	—
4	3,819,151	12,145,949	15,965,100	—	—	—
6	1,770,257	11,654,106	13,424,363	7,778,531	35,257,688	43,036,219
8	869,169	7,093,263	7,962,432	7,154,068	55,574,242	62,728,310
10	490,867	3,096,122	3,586,989	6,619,259	42,449,694	49,068,953
12	248,122	1,084,357	1,332,479	5,099,105	22,076,945	27,176,050
14	89,001	343,471	432,472	2,611,855	9,838,024	12,449,879
16	55,528	79,767	135,295	2,176,062	2,899,648	5,075,710
18	16,010	18,747	34,757	700,748	880,387	1,581,135
20	4,672	9,181	13,853	262,907	561,823	824,730
22	1,482	373	1,855	104,373	18,789	123,162
24	0	932	932	0	65,824	65,824
26	0	499	499	0	53,869	53,869
28	0	227	227	0	26,221	26,221
30+	0	113	113	0	18,913	18,913
Total	13,686,302	43,364,232	57,050,534	32,506,908	169,722,067	202,228,975

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft³		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Stillwater County, MT			
2	1,667,852	4,435,059	6,102,911	—	—	—
4	723,394	7,453,030	8,176,424	—	—	—
6	188,614	3,312,249	3,500,863	573,179	6,423,126	6,996,305
8	23,904	1,373,623	1,397,527	151,346	6,866,352	7,017,698
10	30,701	461,598	492,299	321,136	4,323,529	4,644,665
12	15,551	164,552	180,103	240,596	2,139,667	2,380,263
14	10,194	43,655	53,849	189,484	913,037	1,102,521
16	3,666	9,841	13,507	90,849	250,216	341,065
18	0	3,523	3,523	0	147,979	147,979
20	0	774	774	0	38,774	38,774
22	0	0	0	0	0	0
24	0	0	0	0	0	0
26	0	0	0	0	0	0
28	0	356	356	0	28,340	28,340
30+	0	0	0	0	0	0
Total	2,663,876	17,258,260	19,922,136	1,566,590	21,131,020	22,697,610

APPENDIX II: COST OF HARVEST AND LOADING

II-1 EQUIPMENT HOURLY COSTS, NOT INCLUDING LABOR

Assumptions

For all equipment considered here, depreciation is calculated on a straight-line basis over a 10,000-hour life (5 years), with zero salvage value (except for the miscellaneous support equipment). Repair, maintenance, and fuel and oil costs are assumed equal to depreciation costs. Interest on investment is assumed at 15 percent, and insurance and taxes at 5 percent, of average value of investment (AVI), where:

$$AVI = ([\text{purchase price} - \text{salvage value}] \times 6)/(2 \times 5).$$

Morbell or Bobcat class feller buncher ($90,000 cost; AVI = $54,000)

Depreciation	$9.00	
Repairs, maintenance, fuel, and oil	9.00	
Interest, insurance, and taxes	5.40	
Operating cost/hour		$23.40

Timbco class steep-slope feller buncher ($220,000 cost; AVI = $132,000)

Depreciation	$22.00	
Repairs, maintenance, fuel, and oil	22.00	
Interest, insurance, and taxes	13.20	
Operating cost/hour		$57.20

Grapple skidder of JD-540 class ($85,000 cost; salvage value = $15,000; AVI = $57,000)

Depreciation	$7.00	
Repairs, maintance, fuel, and oil	7.00	
Interest, insurance, and taxes	5.70	
Operating cost/hour		$19.70

Forwarder, timberjack 540 class ($200,000 cost; AVI = $120,000)

Depreciation	$20.00	
Repairs, maintenance, fuel, and oil	20.00	
Interest, insurance, and taxes	12.00	
Operating cost/hour		$52.00

Loader, hydraulic, self-propelled ($90,000 cost; AVI = $54,000)

Depreciation	$9.00	
Repairs, maintenance, fuel, and oil	9.00	
Interest, insurance, and taxes	5.40	
Operating cost/hour		$23.40

Miscellaneous support equipment: service truck, landing crawler tractor, crew truck, etc. ($65,000 cost; salvage value = $25,000; AVI = $49,000)

Depreciation	$4.00	
Repairs, maintenance, fuel, and oil	4.00	
Interest, insurance, and taxes	4.90	
Operating cost/hour		$12.90

II-2 HOURLY COSTS FOR FIVE SYSTEMS, EQUIPMENT ONLY

SYSTEM 1

Morbell or Bobcat feller buncher	$23.40	
Three grapple skidders (1/4-mile skid)	59.10	
Loader	23.40	
Support equipment	12.90	
System cost/hour		$118.80

SYSTEM 2

Same as system 1, except that because of short (1/8-mile) skidding distance only two grapple skidders are required		
System cost/hour		$99.10

SYSTEM 3

Same as system 1, except with half the loader cost (that is, the loader serves two systems)		
System cost/hour		$107.10

SYSTEM 4

Timbco feller buncher	$57.20	
Forwarder (1/4 to 1/2 mile)	52.00	
Loader	23.40	
Support equipment	12.90	
System cost/hour		$145.50

SYSTEM 5

Same as system 4, except with half the loader cost (that is, the loader serves two systems)		
System cost/hour		$133.80

Hourly Operator Wage Costs

Workman's compensation costs are 38 percent of basic wages, and other payroll costs are 12 percent, for a total of 50 percent of basic wage costs.

LOW

Basic wage of $12.00/hour x 1.5	$18.00

HIGH

Basic wage of $15.00/hour x 1.5	$22.50

Hourly System Cost, Including Labor (Low Wage Rate Used)

SYSTEM 1

Equipment	$118.80	
Labor (5)	90.00	
Total cost/hour		$208.80

SYSTEM 2

Equipment	$99.10	
Labor (4)	72.00	
Total cost/hour		$171.10

SYSTEM 3

Equipment	$107.10	
Labor (4.5)	81.00	
Total cost/hour		$188.10

SYSTEM 4

Equipment	$145.50	
Labor (3)	54.00	
Total cost/hour		$199.50

SYSTEM 5

Equipment	$133.80	
Labor (2)	36.00	
Total cost/hour		$169.80

System Production Rates

All of the five systems described have approximately the same productivity (number of trees harvested per 8-hour day) on terrain to which they are suited. Each system should operate in the following range:

- High rate = 1,200 stems per 8-hour day during good weather on favorable terrain with easy access and relatively dense stands.
- Median rate = 900 stems per 8-hour day during adverse weather, with less favorable terrain and access, and lighter stand density.
- Low rate = 600 stems per 8-hour day during severe weather on terrain with access or terrain problems, and light stand density.

Cost Delivered to Landing and Loaded

The cost of harvesting and loading can be expressed in dollars per stem, dollars per cubic foot of stemwood, or dollars per ton of stemwood (ovendry-weight basis), as follows:

Cost Per Stem Delivered to Landing and Loaded

	Production rate		
System	High	Medium	Low
	- - - - - *Dollars/stem* - - - - -		
1	1.39	1.86	2.78
2	1.14	1.52	2.28
3	1.25	1.67	2.51
4	1.33	1.77	2.66
5	1.13	1.51	2.26

Cubic-foot Volume of Stemwood Produced Per Hour Related to D.b.h.

		Volume per hour by production rate		
Tree d.b.h.	Volume per tree	High	Medium	Low
	Ft^3	- - - - - - - - - *Ft*^{3} - - - - - - - - -		
4	2.2	330	248	165
5	3.5	525	394	263
6	5.5	825	619	413
7	7.5	1,125	844	563
8	11.5	1,725	1,294	863
9	15.0	2,250	1,688	1,125

Cost Per Cubic Foot at Landing, Loaded, by System and Production Rate

Average tree d.b.h.	System number				
	1	2	3	4	5
Inches	*Dollars/ft³ of stemwood*				
	High Production Rate				
4	0.64	0.52	0.57	0.60	0.51
5	.40	.33	.36	.38	.32
6	.25	.21	.23	.24	.21
7	.19	.15	.17	.18	.15
8	.12	.10	.11	.12	.10
9	.09	.08	.08	.09	.08
	Median Production Rate				
4	0.84	0.69	0.76	0.80	0.68
5	.53	.43	.48	.48	.43
6	.34	.28	.30	.32	.27
7	.25	.20	.22	.24	.20
8	.16	.13	.15	.15	.13
9	.12	.10	.11	.12	.10
	Low Production Rate				
4	1.27	1.04	1.14	1.21	1.03
5	.79	.65	.72	.76	.65
6	.51	.41	.46	.48	.41
7	.37	.30	.33	.35	.30
8	.24	.20	.22	.23	.20
9	.19	.15	.17	.18	.15

Average Cost Per Dry Ton of Stemwood (80 ft³), at Landing, Loaded, Systems 2 and 5, Median Production Level

Average tree diameter	Dollars per dry ton
Inches	
4	$55.20
5	34.40
6	22.40
7	16.00
8	10.40
9	8.00

APPENDIX III: DEVELOPMENT OF THE POLE JOIST AND DATA RELEVANT TO BUILDING CODES

CONTENTS

Tree props, rails, and edge-glued panels are not products that require approval by agencies that administer building codes for successful introduction into the market. Although lodgepole pine studs are subject to building codes, they are so well accepted that a new producer of such studs will have no difficulty with acceptance by code inspectors or the building trades. Similarly, oriented-strand board is now a product recognized and accepted by major building code agencies when manufactured under strict quality control and periodically tested to ensure compliance with the American Plywood Association (1980) performance standards for sheathing and combination subfloor and underlayment.

The fabricated pole joists that are a major product of the proposed operation, however, are new to the marketplace and will require approval by the major code agencies before they can be sold throughout North America. Ultimately, application by the manufacturer should be made to the following code bodies: Building Officials and Code Administrators International; Southern Building Code Congress; and the International Conference of Building Officials.

The balance of this chapter reviews the development of the pole joist and presents a sequence of experimental data supportive of the design values (table 3-3, page 36).

III-1 INCEPTION AND INITIAL TRIALS OF THE CONCEPT

Koch and Burke (1985) conducted an initial experiment in which 16 lodgepole pine joists were fabricated in 16-foot lengths and tested, as follows (fig. III-1):

- Two flange styles, round and half-round.
- Two web materials (lodgepole pine plywood and lodgepole pine flakeboard).
- Four replications (an equal number of flanges for these replications were cut from each of two Montana locations (3,750 feet elevation near Seeley Lake, and 4,500 feet near Superior).

The plywood for webs was three-ply C-DX sheathing made from 1/8-inch lodgepole veneers rotary-peeled and fabricated in Bonner, MT. When glued, the plywood had an average density of 29.9 lb/ft^3 based on ovendry weight and volume. Actual plywood thickness, measured at test, averaged 0.380 inch.

The flakeboard for webs was manufactured at the Seimpelkamp plant in West Germany from lodgepole pine shipped green from the Bitterroot Valley in Montana. The flakeboard was nominally three-eighths inch thick, with random orientation of flakes. Face flakes were 0.018 inch thick and 3 inches long; core flakes were 0.023 inch thick and 1.5 inches long. The panels were bonded with phenol-formaldehyde resin and hot-pressed to an

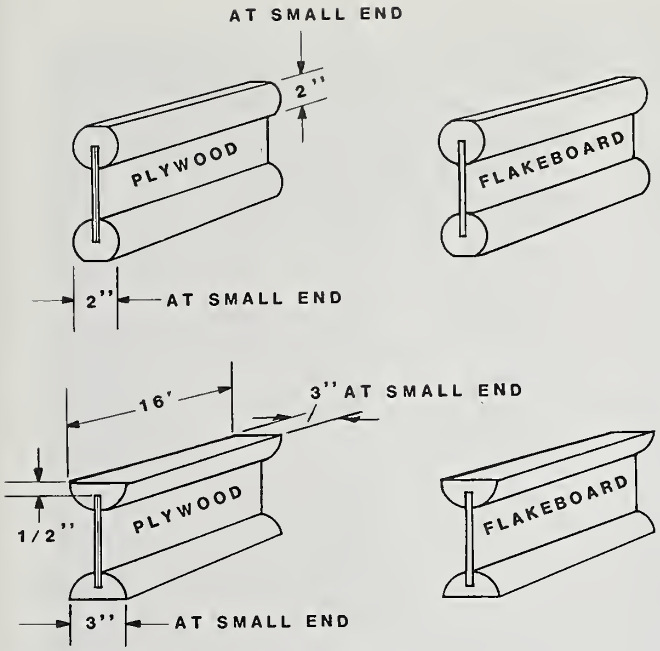

Figure III-1—Fabricated lodgepole pine joists in the initial experiment (Koch and Burke 1985) utilized both round and half-round flanges. Later experiments resulted in abandonment of the half-round flanges and concentration on round or semiround flanges.

average density of 46 lb/ft^3, based on ovendry weight and volume. Actual thickness, measured at test, averaged 0.398 inch.

Lodgepole pine trees for flanges were selected to be straight—usually with less than 2 inches sweep in the 17-foot length of interest. For the round flanges, required small-end diameter was 2 inches plus one-fourth inch minus 0; large-end diameters varied from 2.48 to 3.56 inches. The round flanges were unmachined except for grooving on one side to receive the web and slight flattening on the opposite side to provide a nailing surface.

As originally conceived and tested in the factorial experiment just outlined, two designs were described. The first of these designs utilized rounds for flanges, while the second used half-rounds (fig. III-1). For a variety of reasons explained in Burke and Koch (1987), the second design was dropped in favor of the first. Subsequent discussion and data relate, therefore, only to fabricated joists with round (or semiround) flanges.

Moisture contents at test and specific gravities (based on ovendry weight and volume) of the joist components were as follows:

Item	Moisture content	Specific gravity
	Percent	
Flanges		
in joists with plywood webs	10.0	0.46
in joists with flakeboard webs	10.1	.44
Plywood webs	8.1	.48
Flakeboard webs	7.9	.74

When tested to failure in flexure over a 15-foot span with load applied at two points 40 inches apart and symmetrical about the midlength of the joist, the two types of 9.5-inch-deep joists carried loads as follows (derived from table III-1):

Statistic	Web type: Plywood	Web type: Flakeboard
Load at failure, pounds		
Average	4,076	5,140
Standard deviation	308	372
95 percent exclusion limit	3,250	4,143
95 percent exclusion limit/2.1	1,548	1,973
Design resistive moment, foot-pounds	4,515	5,755

The values in the two foregoing columns do not differ statistically. The 95 percent exclusion limit was calculated to allow 75 percent probability that at least 95 percent of the strengths (loads at failure) from which the samples were drawn will exceed the values tabulated.

Failures were mostly in the flanges, and were about evenly divided between compression and tension failures (table III-1). It was easier to attain a good web-flange joint with the flakeboard than with the plywood. None of the failures in the joist occurred at joist midlength where a web butt joint was located (the web sections were 8 feet long).

Because of stem taper and irregularities in the lodgepole pine flanges, section modulus varied along the length of each joist. For this reason, and because the mechanical properties of the minimally machined flange material were unknown, section transformations to compute modulus of rupture and modulus of elasticity were not attempted—but stiffness (EI) was evaluated.

The two types of 9.5-inch-deep joists had deflection characteristics as follows (derived from table III-1):

Statistic	Web type: Plywood	Web type: Flakeboard
Deflection per 100-pound load increment, inch		
Average	0.063	0.048
Standard deviation	.005	.003
Average EI, that is, modulus of elasticity x moment of inertia, million inch^2 pounds	179.6	235.8

III-2 WEB MATERIAL—PLYWOOD VS. ORIENTED-STRAND BOARD

The differences tabulated, while not statistically significant—probably because of the few joists tested, suggest that flakeboard webs may yield stronger and stiffer joists than plywood webs of the same thickness and species. There are pros and cons for both materials, however. Additionally, while a three-ply plywood web is moderately uniform in properties, flakeboard properties can vary widely, depending on flake geometry, flake orientation, and board specific gravity and resin content.

In a general sense, plywood is lighter than flakeboard (about 30 lb/ft^3 compared to 40 pounds or more for flakeboard, ovendry-weight basis). Also, plywood is more stable

Table III-1—Maximum load at failure, load at elastic limit, and deflection characteristics of 9.5-inch-deep pole joists with plywood and flakeboard webs. See text for dimensions of flanges and webs. Top and bottom of joists were flattened slightly to provide a nailing surface (Koch and Burke 1985)

Replication, average, standard deviation	Maximum load at failure	Deflection at failure	Load at elastic limit	Deflection per 100-pound load	Failure mode
	Pounds	*Inches*	*Pounds*	*Inch*	
		Plywood webs			
1	4,015	2.54	3,400	0.060	Tension
2	3,780	2.35	3,700	.060	Tension
3	4,510	2.89	3,800	.060	Tension
4	4,000	2.81	3,900	.070	Compression
Average	4,076	2.65	3,700	.063	
Std. dev.	308	.25	216	.005	
		Flakeboard webs			
1	4,760	2.11	4,760	0.044	Tension
2	5,650	2.67	3,800	.047	Compression
3	5,100	2.65	4,300	.051	Compression-tension
4	5,050	2.44	4,200	.048	Compression
Average	5,140	2.47	4,265	.048	
Std. dev.	372	.26	394	.003	

(that is, creeps less) under inplane loads than flakeboard, and has significantly less thickness swell when wetted than flakeboard.

Importantly, however, flakeboard has greater inplane strength and stiffness than plywood. Also, our early experience with the German-made lodgepole pine flakeboard described in the foregoing section indicated that it was easier to get a good glue bond between web and flange with flakeboard than with plywood.

Strength and stiffness of flakeboard are both positively correlated with density of the board; that is, dense flakeboards are stiffer and stronger than less-dense flakeboards. This relationship must be utilized with judgment, however, as joists must be kept as lightweight as possible while retaining required strength and stiffness.

When used as a joist web, flakeboard with random flake orientation exceeds oriented-strand board in both inplane strength and stiffness.

Experimental data are insufficient to determine whether continuous webs are superior to webs comprised of discrete short sections 4 to 8 feet in length.

In summary, it appears that maximum inplane strength and stiffness are to be obtained with flakeboard webs having random flake orientation, but such webs will be heavier, and will swell more in thickness and perhaps have more inplane creep than plywood of the same thickness. Because the integrity of the joint between web and flange must be consistently good to maintain uniform joist strength, surface flakes must be tightly bonded to core flakes to prevent shear failures at web surfaces. Tests of joint strength showed no clear difference in webs of oriented-strand board compared to flakeboard with randomly oriented flakes. On the basis of all these considerations, it was decided that the webs should be of flakeboard, with random flake orientation.

For a comparison of flexural properties of joists with flakeboard and plywood webs subjected to various environmental conditions, see Chen and others (1989).

III-3 STEM DIAMETER VS. COMPRESSION MECHANICAL PROPERTIES

The literature on mechanical properties of unmachined stem sections of very small lodgepole pine trees is sparse. To supply needed data for development of the pole joists, seven small lodgepole pines were cut in the Lubrecht Experimental Forest (about 47 degrees latitude), transported to the University of Montana campus in Missoula, hand peeled with a dull spud, measured, and crosscut to yield 21 compression specimens 6 inches long, each containing a knot cluster—seven each (one from each tree) of diameters 1, 2, and 3 inches. After air drying for 2 months the unmachined specimens were destructively tested in compression parallel to the grain, with results—adjusted to a specimen moisture content of 10 percent of ovendry weight—summarized from Burke and Koch (1986) and figures III-2, III-3, III-4, and III-5 as follows:

Specimen diameter	Modulus of elasticity	Maximum crushing strength	Proportional limit
Inches	$M\ lb/in^2$	Lb/in^2	Lb/in^2
1	1,322	4,850	3,090
2	1,262	5,590	3,760
3	1,728	5,860	3,870

With a couple of exceptions, these values were not significantly different. Where significant differences were observed, results suggested that the 3-inch-diameter sections had superior mechanical properties.

Figure III-2—Typical spiral compression failures passing through knots and knot clusters. Drying checks did not appreciably alter the spiral form of failures. The specimens illustrated are 4 inches in diameter. (From Burke and Koch 1986.)

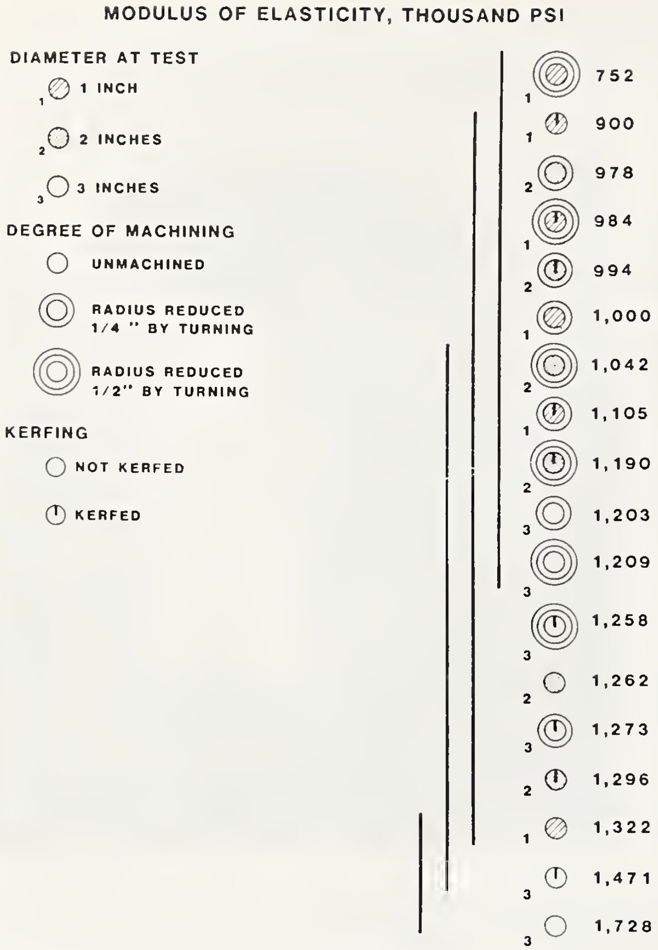

Figure III-3—Specimens from doweling-effects experiment (with key) arrayed according to modulus of elasticity measured in compression parallel to the grain. Values spanned by a single line do not differ significantly at the 0.05 level. (From Burke and Koch 1986.)

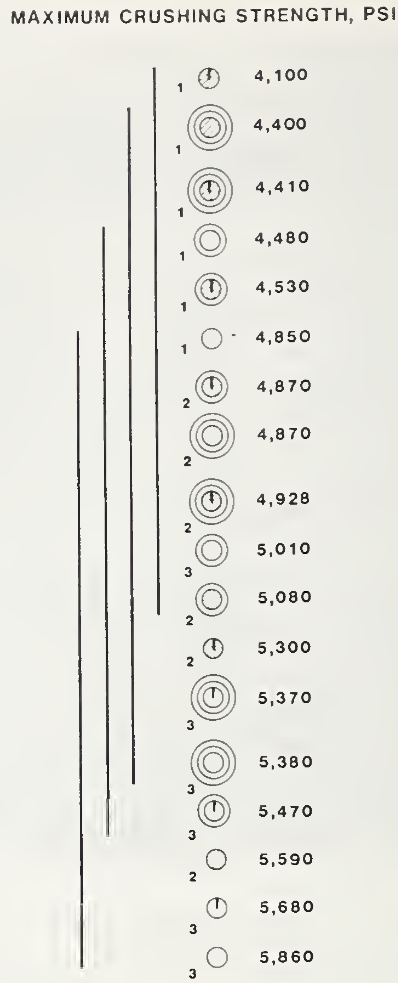

Figure III-4—Specimens from doweling-effects experiment arrayed according to maximum crushing strength parallel to the grain. Values spanned by a single line do not differ significantly at the 0.05 level. See figure III-3 for key. (From Burke and Koch 1986.)

Figure III-5—Specimens from the doweling-effects experiment (same as in figure 10-3) arrayed according to proportional limit in compression parallel to the grain. Values spanned by a single line do not differ significantly at the 0.05 level. See figure III-3 for key. (From Burke and Koch 1986.)

In these compression tests, failures were typically spiral in form, initiated at knots, and progressed from one knot to another (fig. III-2). Some shelling along growth rings was noted.

For lodgepole pine these specimens had fairly wide growth rings; they averaged 14.2 rings per inch. Specific gravity averaged about 0.46 based on ovendry volume and ovendry weight.

III-4 EFFECT OF DOWELING AND KERFING ON MECHANICAL PROPERTIES UNDER COMPRESSION

For uniformity of pole joists in manufacture and use, it seems necessary to reduce tapered stem sections for flanges to uniformly sized dowels; the amount of wood removed during the doweling operation will vary from stem section top to butt, but will frequently be in the range from 0.25- to 0.50-inch radius. Additionally, the dowels must be kerfed (dadoed) to receive the webs. In an effort to assess the effect of such doweling and kerfing on flange mechanical properties, Burke and Koch (1986) matched the specimens described in the previous tabulation with specimens from the same trees kerfed and with either 0.25- or 0.50-inch of radius removed during doweling to achieve machined diameters of 1, 2, and 3 inches. The kerfs (0.125 inch wide, radial to pith) were machined in the dowels while they were still green, and then the specimens were air dried for 2 months. Results of destructive tests in compression parallel to the grain, with values adjusted to a specimen moisture content of 10 percent of ovendry weight, are summarized as follows:

Specimen diameter (inches) and property	Unmachined	Kerfed and doweled, 1/4-inch radius removed	Kerfed and doweled, 1/2-inch radius removed
1 inch			
Modulus of elasticity, M lb/in²	1,322	1,105	984
Maximum crushing strength, lb/in²	4,850	4,530	4,410
Proportional limit, lb/in²	3,090	2,910	2,880
2 inches			
Modulus of elasticity, M lb/in²	1,262	994	1,190
Maximum crushing strength, lb/in²	5,590	4,870	4,928
Proportional limit, lb/in²	3,760	3,670	3,830
3 inches			
Modulus of elasticity, M lb/in²	1,728	1,273	1,258
Maximum crushing strength, lb/in²	5,860	5,470	5,370
Proportional limit, lb/in²	3,870	4,370	3,940

These data suggest that doweling and kerfing have minor effect on proportional limit, but reduce maximum crushing strength by about 10 percent and modulus of elasticity by about 20 percent.

As noted previously, unmachined specimens averaged 14.2 rings per inch. Those with 0.25-inch radius removed averaged 12.0 rings per inch, and those with 0.50-inch radius removed averaged 10.7 rings per inch.

The average maximum crushing stress parallel to the grain of these 42 doweled specimens from Lubrecht Experimental Forest was about equal to the average ultimate tensile stress of eighty-one 2.25-inch-diameter lodgepole pine dowels sampled from throughout the major range of variety *latifolia* (see table III-3).

To confirm the general observations tabulated above, another group of samples were taken at breast height from a stand of lodgepole pine at 3,500 feet elevation located on

a flat between the south end of Hungry Horse Reservoir and Spotted Bear Ranger Station in northwestern Montana (at about 48.5 degrees latitude). Again 6-inch-long compression specimens were prepared: seven were 2 inches in diameter and unmachined (37.6 rings per inch and specific gravity of 0.53 based on ovendry volume and ovendry weight); another seven measured 2 inches in diameter after kerfing to the pith and removal of 0.50 inch in radius during doweling (24.9 rings per inch and specific gravity of 0.49 based on ovendry volume and ovendry weight). Mechanical properties of these compression specimens at 10 percent moisture content were reported by Burke and Koch (1986) as follows:

Property	Unmachined	Kerfed and doweled, 1/2-inch radius removed
Modulus of elasticity, M lb/in^2	1,848	1,410
Maximum crushing strength, lb/in^2	7,738	7,156
Proportional limit, lb/in^2	5,484	4,472

These values for 2-inch-diameter specimens suggest that kerfing and removal of 0.50-inch radius during doweling reduce modulus of elasticity about 24 percent, maximum crushing strength about 8 percent, and proportional limit about 18 percent.

In summary, it is probable that in the range of diameters contemplated for pole joist flanges, kerfing and doweling reduce modulus of elasticity 20 to 30 percent and reduce maximum crushing stress and proportional limit by about 10 percent. Study of figures III-3, III-4, and III-5, and of Burke and Koch (1986, part III) suggests that doweling alone (without kerfing) reduces these mechanical properties by about the same percentages. Kerfing alone (without doweling), however, causes only about half the percentage reductions noted above.

III-5 EXPLORATORY STUDY OF VARIATION IN JOIST PROPERTIES WITH CHANGES IN FLANGE DIAMETER AND JOIST DEPTH

The objective of the experiments described in this section (Burke and Koch 1985) was fabrication and test of joists 9.5, 11.875, 14, and 16 inches deep with doweled flanges in a range of diameters. Webs were locally procured lodgepole pine oriented-strand board—three-eighths inch thick for the joists 9.5 and 11.875 inches deep, and seven-sixteenths inch thick for the joists 14 and 16 inches deep. All flanges had a 1.5-inch-wide flat planed on one side, and a rectangular dado on the opposite side to receive the web—three-fourths inch deep for the joists 9.5 and 11.875 inches deep, seven-eighths inch deep for the 14-inch joists, and 1 inch deep for the 16-inch joist (fig. III-6). The oriented-strand board had relatively low density—about 39.9 lb/ft^3 at a moisture content of about 6 percent of ovendry weight.

The joists were fabricated 26 feet long with a 12/1 glued splice at center length of each flange. Web sections were 4 feet long, but arranged so that one of the web butt joints (one-eighth inch space between web sections) was located at midlength.

Each depth of joist was made with a range of flange diameters (2-inch minimum green diameter and 3.5-inch maximum green diameter) (table III-2). Dowels were dry at time of fabrication so the actual flange diameters were slightly smaller than the nominal green diameters—about 0.10 inch smaller for dowels measuring 2.25 inches when green, and 0.125 inch smaller for dowels measuring 3.0 inches when green.

The joists were loaded to failure, with 24 feet between supports in edgewise-flexure, on a 60,000-pound testing machine equipped with lateral supports to preclude joist buckling. The load was applied at two points 60 inches apart and symmetrical about the midlength of the joist.

The purpose of these essentially unreplicated tests was to gain some empirical data on the relationship between flange diameter, joist depth, and the mechanical properties of EI (modulus of elasticity x moment of inertia—a measure of stiffness), and resistive moment at failure (a function of maximum load).

Data in table III-2 suggested that with the flange shape depicted in figure III-6, target values from table 3-3 could be obtained with dowels turned green to 2.25 inches in diameter for the 9.5-inch joists and 2.5 inches for the 11.875-inch joists.

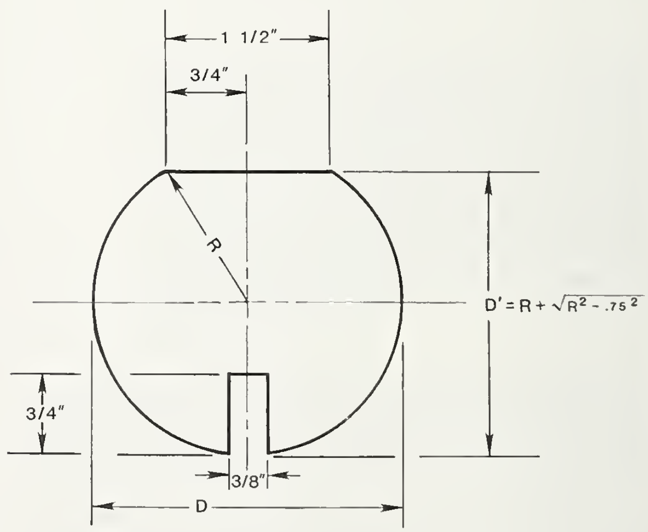

Figure III-6—Diagram of dowel flanges for joists 9.5 and 11.875 inches deep in exploratory tests of joists given 2-point loading over a 24-foot span.

Table III-2--EI and maximum resistive moments (adjusted to moisture content of 10 percent of ovendry weight) of joists 9.5, 11.875, 14, and 16 inches deep with lodgepole pine dowel flanges of various diameters and flakeboard webs

Flange diameter (green)	Number of specimens	At test weight per lineal foot	EI	Maximum load	Maximum resistive moment
Inches		*Pounds*	*Million inch² pounds*	*Pounds*	*Foot pounds*
		9.5-inch-deep joist, 3/8-inch web with 3/4-inch groove depth			
2.0	1	1.8	190	2,600	12,350
2.5	2	2.4	242	3,025	14,368
3.0	1	3.2	322	2,500	11,875
3.5	1	3.5	442	2,900	13,755
		11.875-inch-deep joist, 3/8-inch web with 3/4-inch groove depth			
2.0	1	2.2	265	2,910	13,822
2.5	1	2.4	347	2,455	11,661
		14-inch-deep joist, 7/16-inch web with 7/8-inch groove depth			
2.5	1	3.2	575	4,100	19,475
3.0	2	4.0	754	5,250	24,937
3.5	2	4.9	896	4,350	20,662
		16-inch-deep joist, 7/16-inch web with 1-inch groove depth			
3.0	1	4.3	1,180	4,975	23,631
3.5	1	5.3	1,296	4,400	20,900

Table III-3—Three mechanical properties of *latifolia* stemwood sections extending from 10 to 20 percent of tree height, and equilibrated to 12 percent moisture content—related to latitude (Pellerin and others in preparation)

Latitude	Dynamic MOE[1]	Static MOE[1]	Ultimate tensile stress[2]
Degrees	- - - - *Million lb/in²*	- - - -	*Lb/in²*
40	1.427	1.163	4,120
42.5	1.203	.805	4,060
45	1.233	1.280	4,770
47.5	1.172	.906	4,970
50	1.891	1.519	6,720
52.5	1.754	1.796	5,650
55	1.630	1.565	5,730
57.5	1.366	1.189	4,720
60	1.725	1.455	5,680
Average	1.489	1.298	5,158

[1]Determined in unmachined stem sections.
[2]Determined from stem sections necked down to 2.25 inches in diameter, including knots present.

III-6 GEOGRAPHIC VARIATION OF SPECIFIC GRAVITY AND MECHANICAL PROPERTIES OF LODGEPOLE PINE STEMWOOD

In North America the range of lodgepole pine extends from below 40 degrees latitude to north of 60 degrees latitude, and across more than 10 degrees of longitude at each latitude—mostly centered on the Rocky Mountains (figs. 2-2 and III-7). With such a broad distribution it is not surprising that specific gravity, and therefore mechanical properties, of stemwood of the species varies with geographic location. The discussion that follows is concentrated on three aspects of this variation: (1) the variation in specific gravity of stemwood of lodgepole pine varieties *latifolia* and *murrayana*, the varieties of primary importance to this analysis; (2) the variation in modulus of elasticity and tensile strength of stemwood sections from trees 3 inches in d.b.h. over the North American range of the varieties; and (3) the variations observed in the United States only in mechanical properties of unmachined stemwood sections of lodgepole pine in compression parallel to the grain.

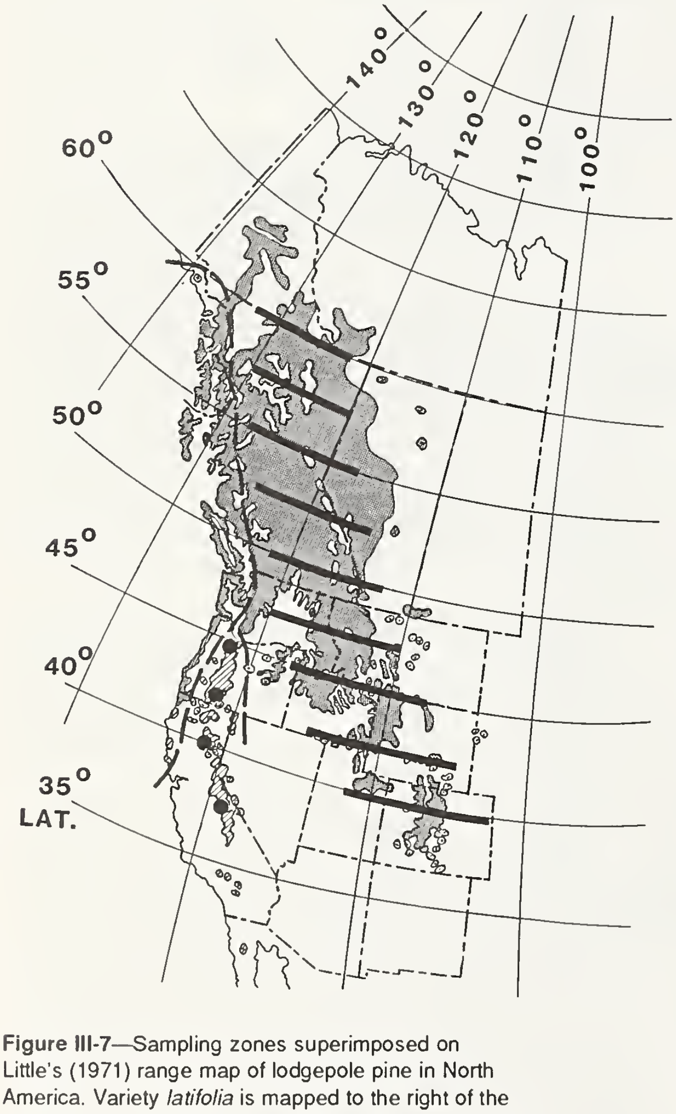

Figure III-7—Sampling zones superimposed on Little's (1971) range map of lodgepole pine in North America. Variety *latifolia* is mapped to the right of the dashed lines, *murrayana* between them, and *contorta* to the left of them. Variety *contorta* was not studied because of its small potential for commercial use.

Locating and Selecting the 243 *Latifolia* Trees in North America

The sample area spanned from 40 to 60 degrees (inclusive) at 2.5-degree intervals; the width of the sample area was 10 degrees of longitude, with sample area shifting 2.5 degrees west for each 2.5 degrees shift north in latitude (fig. III-7). Sample band width was 0.5 degree of latitude on each side of the nominal latitude line; for example, each latitude band was 1 degree deep in the north-south direction (60 nautical miles), and 10 degrees of longitude wide in the east-west direction.

Within each of these nine latitudinal sampling bands, natural unthinned stands were identified with the following constraints: adjacent to road traversable by pickup truck; within boundaries of National or Provincial Forests; and containing some more-or-less level benches or flats.

It was found that at least nine such stands could be identified within each sampling band. The identified stands were ranked by elevation, and then the three highest, the three most intermediate, and the three lowest were selected for sampling. These elevational zones were highest in the south and lowest in the north; elevational zone width was broadest at midlatitude (fig. III-8).

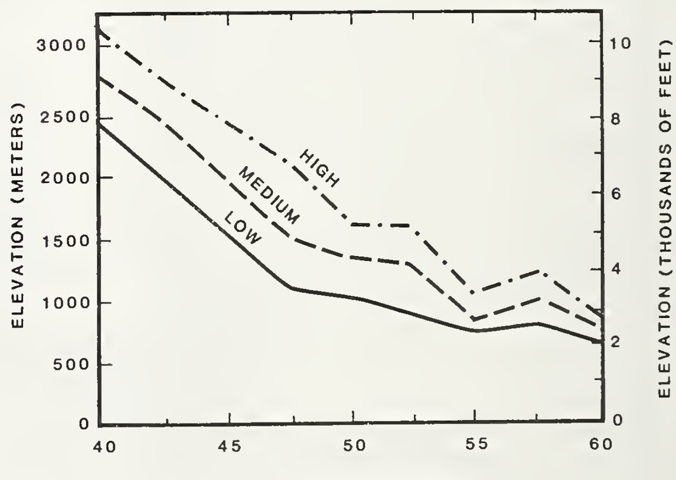

Figure III-8—Elevational trends in the three zones (low, medium, and high) where lodgepole pine (var. *latifolia*) was sampled along nine latitudes. Each plotted point is the average for nine trees; that is, three diameters by three replications (Koch 1987, p. 6).

On a bench or flat typical of each of these selected stands, single trees 3 inches, 6 inches, and 9 inches in d.b.h. and free of insects and diseases were taken that, in the collector's view, typified within-stand trees of these diameters on that bench or flat. Thus, 27 *latifolia* trees were taken from each of the nine latitudes—3 diameters x 3 elevations x 3 replications, for a total of 243 trees.

It is important to note that this sampling scheme resulted in selection of 3-, 6-, and 9-inch trees that were of approximately the same age because most of the stands were of fire origin. Thus, most of the small-diameter trees were suppressed, while the larger trees were the fast growers.

For a complete description of the field and laboratory work see Koch (1987, p. 9).

Locating and Selecting the 36 *Murrayana* Trees in North America

The sample areas extended from 37½ to 45 degrees latitude at 2.5-degree intervals; for example, trees were sampled at 37½, 40, 42½, and 45 degrees—but only at one longitude per latitude (fig. III-7).

The same three constraints on location applied to *latifolia* also applied to *murrayana*, but *murrayana* was sampled only from midelevation, as follows:

Latitude	Elevation
Degrees	*Feet*
37½	7,880
40	5,499
42½	6,581
45	3,766

Thus, nine *murrayana* trees were taken from each of the four latitudes—3 diameters x 1 elevation x 3 replications, for a total of 36 trees.

For a complete description of the field and laboratory work see Koch (1987, p. 9).

Specific Gravity (North America)

Latifolia—With all data pooled, stemwood (from 6-inch high-stump to apical tip) specific gravity based on ovendry weight and green volume averaged 0.418, with standard deviation of 0.032. It was unrelated to elevational zone, but negatively correlated with d.b.h. as follows (fig. III-9):

D.b.h.	Average specific gravity	Standard deviation
	Inches	
3	0.427	0.037
6	.419	.028
9	.407	.026

Stemwood specific gravity was positively correlated with latitude so that specific gravity increased with increased latitude to the Canadian border and then was more-or-less constant but with some diminution at extreme northern latitudes (fig. III-9) as follows:

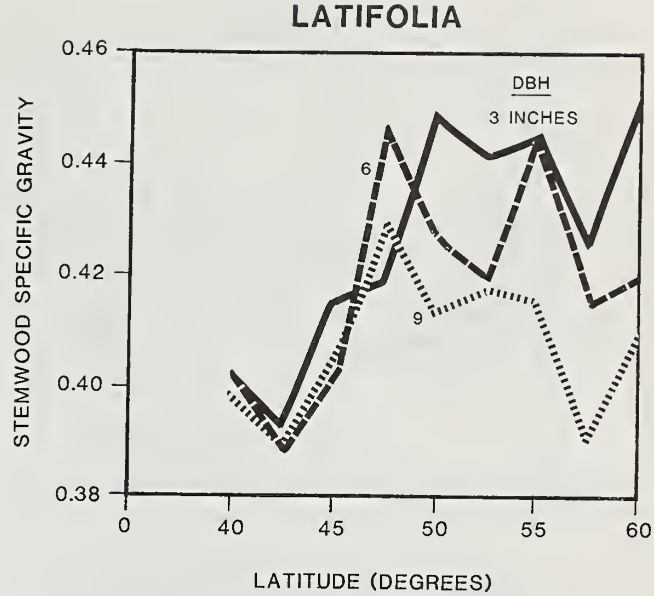

Figure III-9—Specific gravity of stemwood (6-inch stump height to apical tip), based on ovendry weight and green volume, of *latifolia* trees of three diameters related to latitude (Koch 1987, p. 178).

Latitude	Specific gravity
Degrees	
40	0.401
42.5	.390
45	.408
47.5	.431
50	.430
52.5	.426
55	.435
57.5	.410
60	.427

Average specific gravity (basis of ovendry weight and green volume) of entire stemwood from 6-inch stump height to apical tip in *latifolia* trees of the diameters studied can be closely estimated from the specific gravity of a complete stemwood disk taken at 20 percent of tree height, by the following relationship (R^2 = 0.878; standard error of estimate = 0.011):

Average stemwood specific gravity = 0.07524 + 0.82479 (stemwood specific gravity at 20 percent of tree height)

Stemwood specific gravity diminishes curvilinearly from stump top to near the base of the live crown, above which it remains more-or-less constant—or increases slightly (fig. III-10). Variation patterns were similar for the three tree diameters studied, but the level of the curves varied significantly with diameter—that is, at all heights small-diameter trees had higher stemwood specific gravity than large trees. At 60 percent of tree height, that is, just above the base of the live crown, stemwood

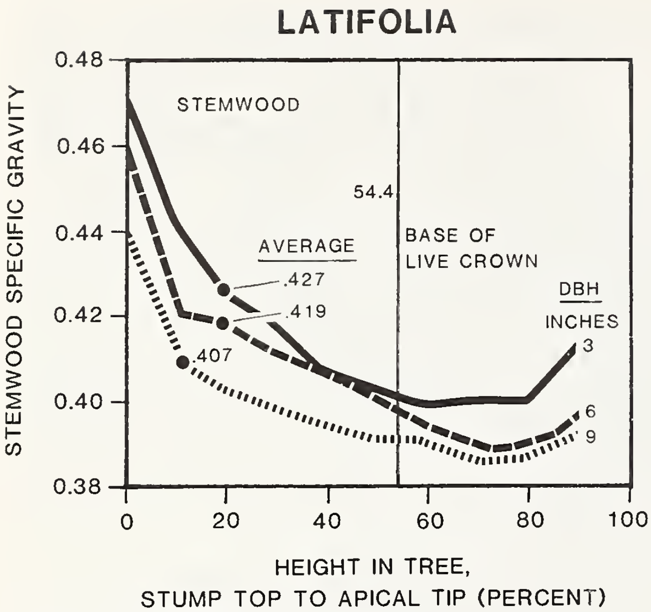

Figure III-10—Specific gravity of stemwood (based on ovendry weight and green volume) of *latifolia* trees of three diameters related to height in tree and base of live crown (Koch 1987, p. 180).

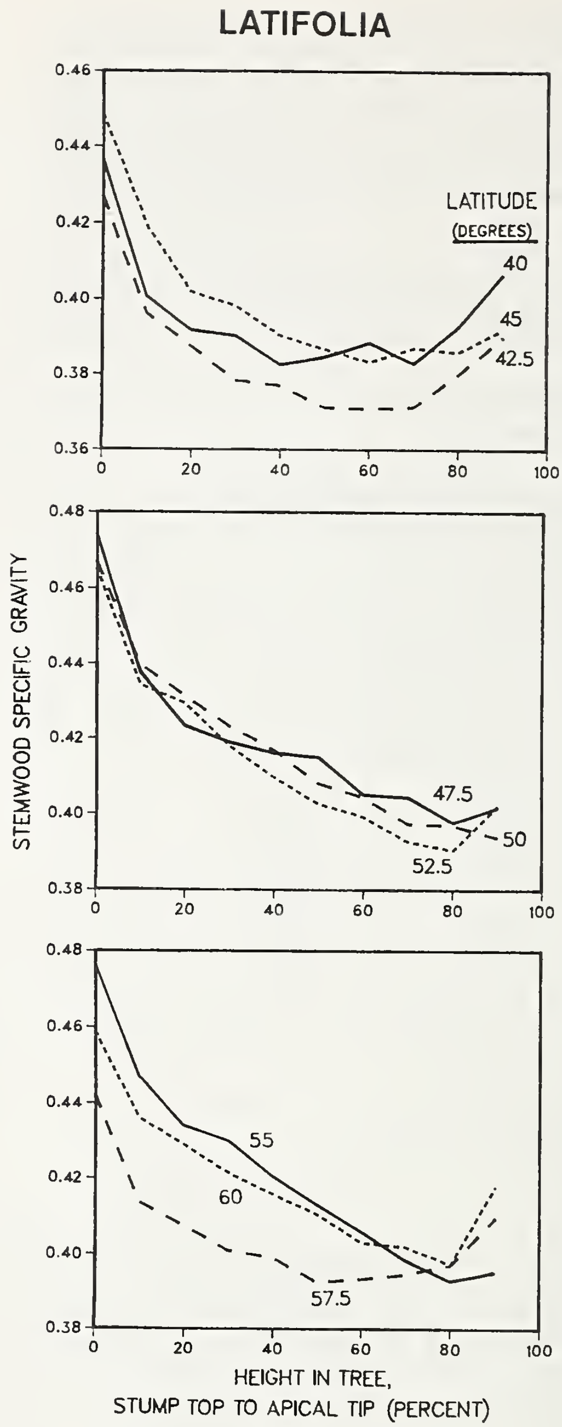

Figure III-11—Stemwood specific gravity (based on ovendry weight and green volume) of *latifolia* trees related to height in tree and latitude (Koch 1987, p. 181).

specific gravity differed little with diameter, however, averaging 0.399, 0.395, and 0.391 for trees 3, 6, and 9 inches in diameter.

With diameter data pooled, stemwood specific gravity relationships to height in tree also differed significantly with latitude (fig. III-11).

Murrayana—Average entire stemwood specific gravity was inversely correlated with average growth-ring width at 6-inch stump height (R^2 = –0.490); that is, fast-growing trees had lower specific gravity than slow growers.

Average specific gravity (based on ovendry weight and green volume) of entire stemwood from 6-inch-high stump top to apical tip in *murrayana* trees can be closely estimated from specific gravity of a stemwood disk taken at 20 percent of tree height (figs. III-12 and III-13) by the following relationship (R^2 = 0.937; standard error of the estimate = 0.012):

Average stemwood specific gravity = 0.0917 + 0.8014 (stemwood specific gravity at 20 percent of tree height)

For trees 6 and 9 inches in d.b.h., average stemwood specific gravity was least in the southernmost latitude.

Average stemwood specific gravity was inversely correlated with d.b.h., as follows:

D.b.h.	Average specific gravity	Standard deviation
Inches		
3	0.482	0.039
6	.440	.042
9	.407	.031

In *murrayana* trees, stemwood specific gravity curvilinearly diminishes above stump height to near the base of the live crown (figs. III-12 and III-13). At all percentages of tree height below 90 percent, stemwood specific gravity is negatively correlated with tree d.b.h. (fig. 10-12). Stemwood specific gravity at 20 percent of tree height approximates stemwood average specific gravity (fig. III-13).

Comparison of *Latifolia* With *Murrayana*—Specific gravity of entire stemwood of *murrayana* was found to be greater than that of *latifolia* at the three latitudes sampled in common (40, 42.5, and 45 degrees—in midelevational zones), as follows:

D.b.h.	*Latifolia*	*Murrayana*
Inches		
3	0.409	0.482
6	.396	.454
9	.396	.412
Average	.395	.441

With diameter data pooled from the three latitudes common to the two varieties, the difference was observable at all percentages of tree heights (fig. III-14).

In more northerly latitudes, *latifolia* stemwood has higher specific gravity than the values tabulated above (fig. III-9).

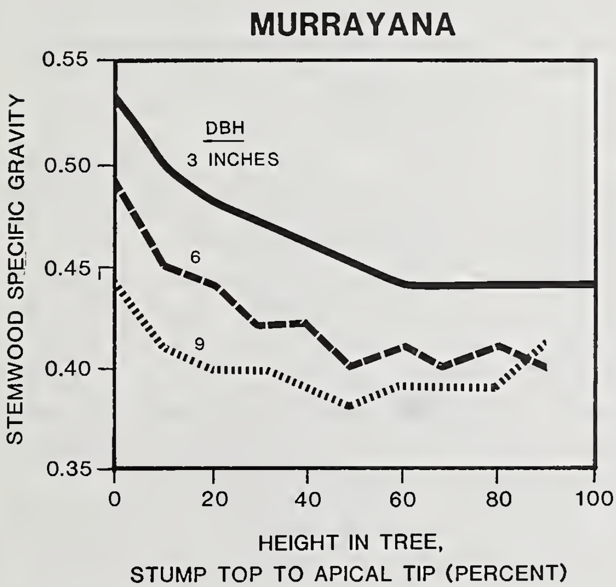

Figure III-12—Stemwood specific gravity (based on ovendry weight and green volume) for m*urrayana* trees of three diameters, related to height in tree (Koch 1987, p. 228).

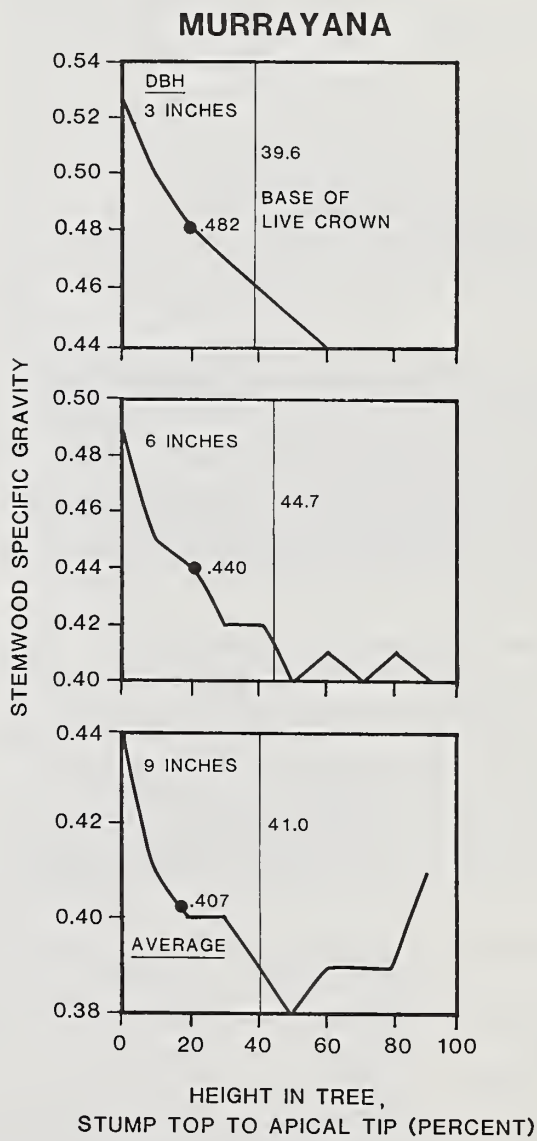

Figure III-13—Stemwood specific gravity (based on ovendry weight and green volume) for *murrayana* trees of three diameters, related to height in tree, position of crown base, and position and value of stem-average stemwood specific gravity (Koch 1987, p. 228).

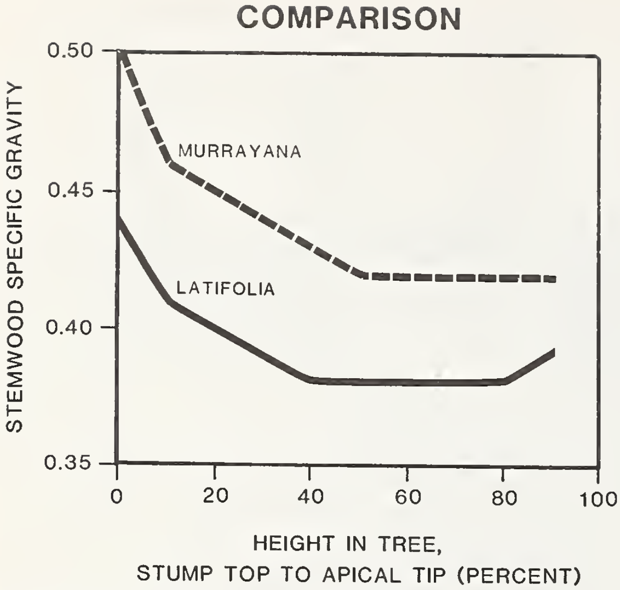

Figure III-14—Specific gravity of stemwood, ovendry weight and green volume basis; *latifolia* compared to *murrayana* at latitudes 40, 42.5, and 45 degrees in midelevation zones, as related to height in tree (Koch 1987, p. 242).

Modulus of Elasticity of Unmachined Stemwood Sections (North America)[1]

From the trees 3 inches in d.b.h. collected in North America as just described (fig. III-7), stemwood sections between 10 and 20 percent of tree height were removed for evaluation in compression and tension. Evaluated, therefore, were stem sections from 81 *latifolia* and 12 *murrayana* trees.

Data from *Latifolia* and *Murrayana* Pooled—The stem sections, unmachined and equilibrated to 12 percent moisture content, were nondestructively evaluated for static modulus of elasticity (MOE) in compression parallel to the grain, and dynamic MOE computed from stress wave propagation times. Specific gravity of the stem sections (based on ovendry weight and volume at 12 percent moisture content) was also determined. Relationships between these properties were as follows (MOE in million lb/in^2):

Specific gravity = 0.50352858 + 0.03149713 (dynamic MOE) $R = 0.2502$

Specific gravity = 0.52331942 + 0.02033634 (static MOE) $R = 0.2154$

Static MOE = 0.17581132 + 0.74253811 (dynamic MOE) $R = 0.5565$

***Latifolia* vs. *Murrayana* Modulus of Elasticity**—Sampling latitudes in common for the two varieties were 40, 42$^1/_2$, and 45 degrees (fig. III-7) at medium elevation. Within these common sampling zones, only at 40 degrees did the two differ significantly, and then only in dynamic MOE; *latifolia* had significantly higher dynamic MOE (1.420 million lb/in^2) than *murrayana* (0.837 million lb/in^2).

For *murrayana*, dynamic MOE was positively correlated with latitude, with values at 45 degrees (1.303) and 42.5 degrees (1.174) significantly greater than at 37.5 degrees (0.665); the value at 40 degrees did not differ significantly from values at the other three latitudes.

Latifolia—While a general positive correlation with mechanical properties and latitude was discernible, anomalies in the data from 40 and 47$^1/_2$ degrees latitude made statistical interpretation of the data difficult (table III-3).

Static MOE at 52.5 degrees (1.796) was significantly greater than at 45 degrees (1.280), 57.5 degrees (1.189), 40 degrees (1.163), 47.5 degrees (0.906), and 42.5 degrees (0.805). Static MOE was significantly less at 47.5 and 42.5 degrees than at the other latitudes.

Ultimate Tensile Strength of Doweled Stemwood (North America)[1]

Following nondestructive static and dynamic modulus of elasticity evaluations of the unmachined stem sections, they were turned to 2.25 inches in diameter and tested to destruction in tension.

***Latifolia* and *Murrayana* Data Pooled**—Relationships between the modulus of elasticity values and specific gravities of the unmachined sections, and the ultimate tensile stress of the 2.25 inch dowels machined from the stem sections were as follows:

Ultimate tensile stress = 3308.82333 + 1448.31302 (static MOE) $R = 0.4910$

Ultimate tensile stress = 2152.90980 + 2065.23983 (dynamic MOE) $R = 0.5248$

Ultimate tensile stress = –361.68961 + 9951.77743 (spec. grav.) $R = 0.3184$

In the foregoing equations, ultimate tensile stress is in lb/in^2, modulus of elasticity is in million lb/in^2, and specific gravity is based on ovendry weight and volume at 12 percent moisture content.

***Latifolia* vs. *Murrayana* Ultimate Tensile Strength**—Ultimate tensile stress did not differ significantly between the two varieties—a somewhat surprising result in view of the higher specific gravity of *murrayana* at latitudes sampled in common with *latifolia*.

Latifolia—Ultimate tensile stress (table III-3) of specimens from latitude 50 degrees (6,720) averaged significantly higher than in those from 47.5 degrees (4,970), 45 degrees (4,770), 57.5 degrees (4,720), 40 degrees (4,120), and 42.5 degrees (4,060).

Ultimate tensile stress in specimens from the southernmost two zones (40 degrees and 42.5 degrees) averaged significantly lower than in specimens from 50 degrees and more northerly latitudes.

[1]Data under these headings are from Pellerin and others (in preparation).

Additionally, ultimate tensile stress was inversely correlated with elevational zone, as follows:

Elevational zone	Ultimate tensile stress
	Lb/in²
Low	5,590
Medium	5,390
High	4,500

Ultimate tensile stress in the doweled sections was positively correlated with dynamic modulus of elasticity of the unmachined sections (fig. III-15). The lower 5 percent exclusion limit for the ultimate tensile stress values was 2,035 lb/in², from which a design value of tension parallel to the grain of 970 lb/in² can be derived. When the stem sections were screened by dynamic modulus of elasticity to various threshold values, lower 5 percent exclusion limits and design values were as follows:

Dynamic MOE threshold	Average	Tensile stress 5 percent exclusion limit	Design stress
Million lb/in²		*Lb/in²*	
1.25	5,716	2,940	1,400
1.50	5,990	3,050	1,452
1.60	6,200	3,280	1,562

Compression Properties of Unmachined Stemwood Sections (United States)

As noted previously, flange failures in the pole joists tested were about evenly divided between tension and compression fractures. To provide additional statistical data descriptive of the variation in compression strength of dowels from small lodgepole pines within the major range of the species in the United States, a pair of dominant or codominant lodgepole pine trees 3.5 to 4 inches in d.b.h. were selected for sampling at each of 28 locations in seven western States (fig. 2-2 and table III-4). No trees were sampled in California because public land managers indicated that small lodgepole pine trees in that State were not in excess supply.

A 9-inch-long stem section was removed at 20 percent of tree height from each of the 56 trees. This height was selected because previous research (Koch 1987) showed that the specific gravity of stemwood sampled at 20 percent of tree height closely approximates the average for entire stemwood (fig. III-10).

These stem sections were debarked, air-dried, lathe-turned to 2¼ inches in diameter, and square-end trimmed to remove chuck marks.

All but two of the turned specimens included knot clusters. No knots exceeded 0.5 inch in diameter, and most measured 0.2 to 0.3 inch in diameter. Most were sound red knots, but some were encased.

At test, the specimens averaged 8.2 percent moisture content (based on ovendry weight), with standard deviation of 0.63 percentage points and range from 6.4 to 9.5 percent. Of the 56 specimens, 30 had at least one drying check, and 26 were check free.

Compresssion tests parallel to the grain were conducted according to ASTM D-198 (American Society for Testing and Materials 1972b) on the 60,000-pound universal testing machine of the University of Montana School of Forestry. The machine was fitted with a compressometer with 4-inch gage length and dial gage reading to 0.0001 inch. Moisture content at test and specific gravity (based on ovendry weight and volume at test) were determined.

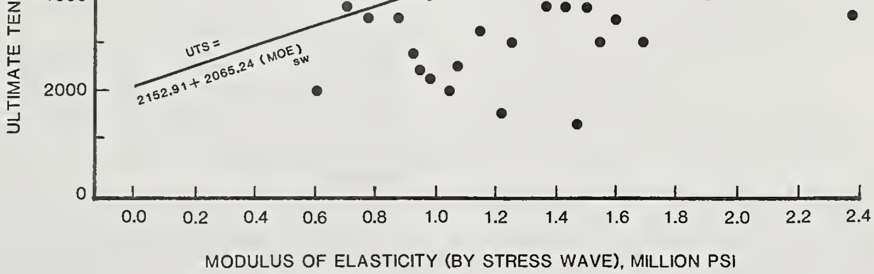

Figure III-15—Scatter diagram and regression line of modulus of elasticity of stem sections (one-tenth to two-tenths tree height) from 81 *latifolia* trees 3 inches in d.b.h. versus ultimate tensile stress of 2.25 inch-diameter pith-centered dowels turned from the stem sections Pellerin and others (in preparation).

Table III-4—Test-specimen characteristics tabulated by State averages and ranked by modulus of elasticity; standard deviations shown in parentheses (data from Koch and Barger 1988)

State	Number of specimens	Modulus of elasticity	Maximum crushing strength	Proportional limit	Specific gravity[1]	Rings per inch
		Million lb/in²	*Lb/in²*	*Lb/in²*		
Montana	10	1.63 (0.26)	7,120 (1,048)	4,930 (798)	0.492 (0.035)	32 (7)
Washington	8	1.24 (.26)	5,590 (827)	3,970 (568)	.442 (.038)	25 (12)
Wyoming	8	1.14 (.23)	5,430 (738)	3,550 (672)	.453 (.025)	36 (6)
Colorado	10	1.11 (.18)	5,690 (518)	4,340 (613)	.466 (.022)	56 (36)
Idaho	12	1.05 (.27)	5,340 (592)	3,410 (968)	.444 (.040)	20 (10)
Utah	2	1.02 (.60)	5,130 (92)	3,380 (806)	.413 (.004)	35 (16)
Oregon[2]	6	.93 (.28)	5,300 (745)	2,530 (996)	.506 (.063)	28 (6)

[1]Based on ovendry weight and volume at 8.2 percent moisture content.
[2]Only the two specimens from the Malheur National Forest were free of compression wood; they had average modulus of elasticity of 1.24 million lb/in², with specific gravity of 0.456 and 23 rings per inch.

The compressometer was placed so that the knot cluster present in each specimen (except for two which were knot free) was within the gage length.

Values for modulus of elasticity, maximum crushing strength, and proportional limit were adjusted to a specimen moisture content of 10 percent by the procedure specified in ASTM D-2915 (American Society for Testing and Materials 1972a).

Mechanical properties, in compression parallel to the grain, of the 56 specimens gathered from the 28 areas in seven States are summarized as follows (values adjusted to a specimen moisture content of 10 percent of ovendry weight):

Property	Average value	Standard deviation	Range
	Lb/in²		
Modulus of elasticity	1,190,000	320,000	640,000-2,090,000
Maximum crushing strength	5,760	967	4,280-8,730
Proportional limit	3,850	1,039	1,060-6,080

The data (see Koch and Barger 1988, appendix) suggest that mechanical properties in compression parallel to the grain are not closely related to specific gravity, rings per inch, or the presence of drying checks.

This lack of correlation with specific gravity is largely attributable to the presence of knot clusters in the specimens and, more important, to the sporadic presence of compression wood. Compression wood generally has high specific gravity, but—in dry wood—low mechanical properties. Also, trees that are fast growers may have more compression wood than the slow growers. For example, the two trees sampled from the Pinhead Butte area of the Mt. Hood National Forest in Oregon both had much compression wood and had average modulus of elasticity of only 760,000 lb/in², with proportional limit of only 1,460 lb/in², even though they had the highest specific gravity of any trees sampled (average 0.580); these two specimens had 32 and 26 rings per inch.

Differences in mechanical properties between specimens free of compression wood and those with compression wood readily visible in sanded cross sections are indicated in the following tabulation:

Property	No visible compression wood (42 specimens)	Visible compression wood (14 specimens)
	Lb/in²	
Modulus of elasticity		
Average	1,270,000	940,000
Standard deviation	299,000	250,000
Range	870,000-2,090,000	640,000-1,430,000
Maximum crushing strength		
Average	5,920	5,250
Standard deviation	986	722
Range	4,280-8,730	4,390-6,770
Proportional limit		
Average	4,130	3,030
Standard deviation	855	1,134
Range	2,620-6,080	1,060-5,110

While data are far from adequate to characterize small lodgepole pines in the several States studied—particularly those of Utah where only two trees were sampled—a ranking of the States by specimens' average modulus of elasticity suggests that lodgepole pine in Montana's study areas have superior mechanical properties (table III-4).

Implications of Geographic Variations

Study of the variation in specific gravity, and tension and compression properties of lodgepole pines sampled broadly within the North American range of the species, suggests that these physical and mechanical properties of stemwood from small trees are maximum, or near maximum, in northwestern Montana close to the Canadian border. Additionally, data available on mechanical properties of stemwood from seven northwestern States (table III-4) support this conclusion.

III-7 VARIATION IN MODULUS OF ELASTICITY OF LODGEPOLE PINE DOWELS FROM NORTHWESTERN MONTANA (LATITUDE 48.5 DEGREES)

As noted in section 4-1, Burke and Koch (1987) collected 152 small lodgepole pines in the Libby to West Glacier area of Montana, and from these stems turned 16-foot-long dowels with green diameters of 2.25 and 2.50 inches—76 of each diameter. The 2.25 inch dowels had average specific gravity of 0.42; dowels 2.50 inches in diameter had average specific gravity of 0.43—both values based on ovendry weight and green volume.

Modulus of elasticity data gathered on these dowels, by nondestructive evaluation in flexure over a 15-foot span with center-point loading, are summarized as follows:

Moisture content and statistic	**Dowel diameter 2.25 inches**	**2.50 inches**
	Million lb/in²	
Green		
Average	1.446	1.553
Standard deviation	.235	.195
Range	0.937-2.026	1.081-1.985
10 percent moisture content		
Average	1.739	1.850
Standard deviation	.262	.251
Range	1.16-2.376	1.322-2.460

The 2.50-inch dowels had slightly higher average modulus of elasticity than the 2.25-inch dowels.

Distributions of values were more-or-less normal (figs. 4-1 and 4-2).

III-8 SEMISQUARING OF DOWELS—EFFECT ON MECHANICAL PROPERTIES

Because of the need to use blocking in lengths precision trimmed to fit between joists, it was deemed desirable that flanges be machined to a precise width in addition to being flattened on top to provide a nailing surface and provided with a dado groove for the web (fig. III-16). It was surmised that this additional machining would further reduce the mechanical properties of the dowels. To evaluate the anticipated effect, end-matched replicates of cylindrical and semisquared and grooved (fig. III-16) dowels 2.25 and 2.50 inches in diameter (green dimensions) were prepared in 6-inch lengths and tested (when dry) in compression parallel to the grain.

Average modulus of elasticity of the semisquared and grooved dowels was less than that of the cylindrical dowels. Missing data in the 2.5-inch tabulation (table III-5) makes evaluation difficult, but it is probable that semisquaring and grooving operations reduce MOE by at least 5 percent, and possibly more.

Ultimate crushing stress was little affected (table III-5).

III-9 FIRST APPROXIMATION OF JOIST DESIGNS—DESTRUCTIVE TESTS OF 63 JOISTS

To gather empirical data that would give some indication of the joist dimensions required to meet the target properties outlined in table 3-3, the dowels with green diameters of 2.25 and 2.50 inches described in section III-7 were machined to the cross sections depicted in figure III-16. At time of machining, the dry dowels averaged 2.15 and 2.38 inches in diameter. They were paired by modulus elasticity class (so that both flanges in a joist had approximately equal moduli of elasticity) and assembled with 3/8-inch-thick webs of lodgepole pine oriented strand board manufactured in an Idaho plant. This oriented strand board weighed about 39.3 lb/ft³ at a moisture content of 10 percent of ovendry weight. Flake thickness and resin content are unknown.

The joists were loaded to failure with 15 feet between supports in edgewise flexure on a 60,000-pound universal testing machine equipped with lateral supports to preclude buckling. The load was applied at two points 60 inches apart and symmetrical about the midlength of the joist. Roller nests were used under both end supports, and a roller nest was placed under one head to ensure that loading was vertical (fig. 3-3). The apparatus and speed of vertical movement of the loading head followed recommendations of American Society of Testing and Materials (1972b).

The joists failed to meet the target values (table 3-3) for EI and design resistive moment; summary statistics derived from table III-6 were as follows:

Joist depth (fig. III-16)	**EI**	**Design resistive moment**
Inches	*Million inch² pounds*	*Foot pounds*
9 1/2	132	2,468
11 7/8	288	3,665

EI and maximum resistive moment of the joists were unrelated to numerical visual grades assigned to the dowels on the basis of their knot structure (R^2 values were less than 0.12). Also, severity of drying checks in the dry flange dowels (numerically rated) was unrelated to EI or maximum resistive moment.

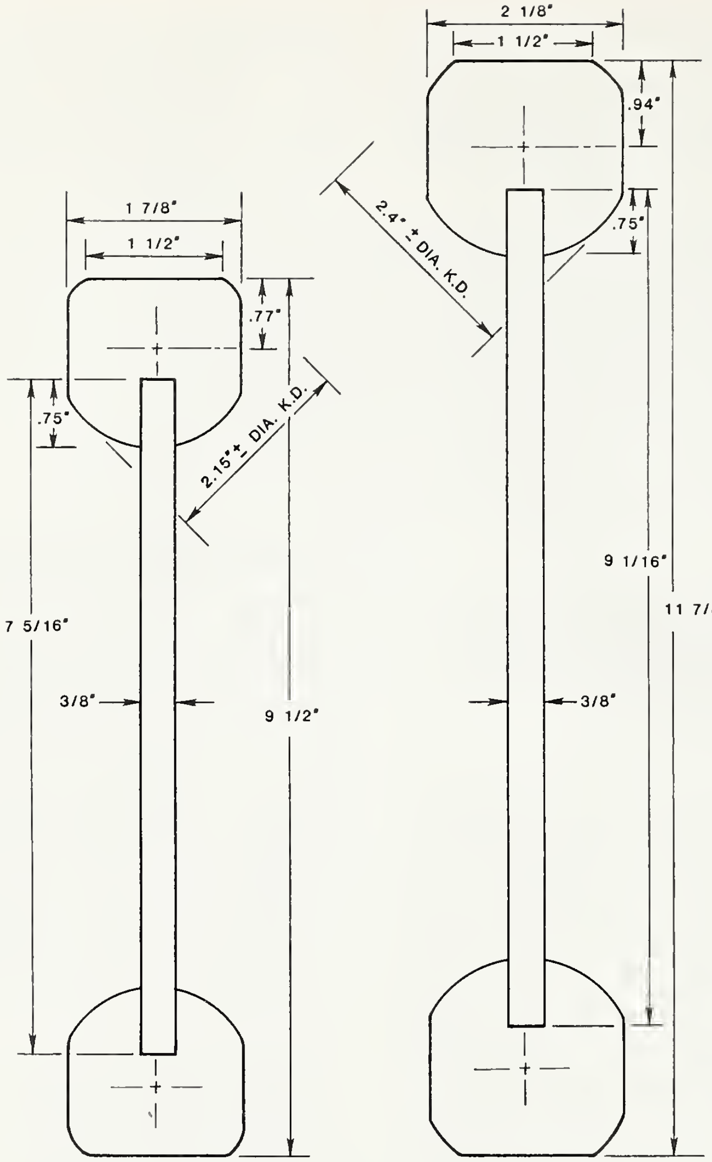

Figure III-16—Joists fabricated $9^1/2$ and $11^7/8$ inches deep, with lodgepole pine pith-centered dowels for flanges and three-eights inch OSB for webs.

Table III-5—Effect on mechanical properties[1] in compression parallel to the grain of semisquaring and grooving—when dry, dowels turned green to 2.25 and 2.50 inches in diameter (fig. III-16)

Specimun number, average, standard deviation	Doweled but not otherwise machined		Semisquared and grooved	
	MOE	Maximum crushing stress	MOE	Maxmum crushing stress
	Million lb/in²	*Lb/in²*	*Million lb/in²*	*Lb/in²*
	Dowels 2.25 inches in diameter			
1	1.014	3,838	0.943	5,030
2	.907	3,887	.893	3,983
3	.914	4,363	.802	3,550
4	.747	3,594	.923	3,383
5	.887	4,727	.956	4,731
6	1.055	4,281	1.098	3,989
7	.888	3,222	.720	3,244
8	1.304	5,192	1.054	4,735
9	1.405	4,200	1.108	4,281
10	1.171	4,637	1.396	4,500
Average	1.029	4,194	.989	4,143
Std. dev.	.207	581	.189	616
n	10	10	10	10
	Dowels 2.50 inches in diameter			
1	2.125	8,144	2.039	9,817
2	1.398	6,286	1.420	6,027
3	1.742	7,445	—	7,383
4	2.737	5,973	1.925	6,286
5	1.826	5,427	—	6,528
6	2.775	6,346	1.487	5,043
7	2.640	5,138	1.781	4,359
8	—	5,675	1.609	4,901
Average	2.178	6,304	1.710	6,293
Std. dev.	.549	1,023	.246	1,730
n	7	8	6	8

[1]Values adjusted to a specimen moisture content of 10 percent of ovendry weight.

Table III-6—Maximum resistive moment and EI of pole joists 9.5 and 11.875 inches deep (fig. III-16), ranked by average modulus of elasticity of the two dowel flanges of each joist (before they were semisquared and grooved); all values adjusted to 10 percent moisture content[1]

Joist	Maximum resistive moment	EI	MOE of dowels (average of both)	Failure type[2]
Number	*Foot-pounds*	*Million inch² pounds*	*Million lb/in²*	
		9.5-inch-deep Joists		
1	8,750	147.029	2.233	C
2	7,975	165.371	2.215	S
3	6,925	173.580	2.162	S
4	7,500	128.126	1.980	C
5	8,750	141.197	1.944	S
6	8,425	150.900	1.939	S
7	7,800	125.493	1.858	T
9	8,400	153.879	1.880	S
8	8,100	119.927	1.802	C
10	7,950	125.362	1.791	C
15	7,425	131.406	1.779	T
16	8,100	124.980	1.770	C
11	7,938	144.230	1.764	T
12	7,750	143.488	1.732	T
13	8,750	128.409	1.719	T
14	6,925	134.051	1.702	S
17	6,938	115.496	1.690	C
18	7,175	110.421	1.688	T
19	5,625	121.042	1.658	T
20	6,975	134.937	1.651	C
21	7,000	127.651	1.628	T

(con.)

Table III-6—(Con.)

Joist	Maximum resistive moment	EI	MOE of dowels (average of both)	Failure type[2]
Number	*Foot-pounds*	*Million inch² pounds*	*Million lb/in²*	
23	8,000	134.805	1.640	T
24	7,950	135.943	1.612	S
22	5,100	122.675	1.606	C
25	7,125	120.269	1.582	T
26	5,925	129.709	1.522	T
28	8,450	121.119	1.416	C
27	8,050	119.166	1.414	C
29	4,700	106.047	1.340	T
30	7,875	119.588	1.242	T
Average	7,478	131.877	1.732	
Std. dev.	1,034	15.350	.235	
Range	4,700-8,750	106-174	1.242-2.233	
95 percent exclusion limit[3]	5,183	—	—	
Design value[4]	2,468	131.877	—	
		11.875-inch-deep Joists		
1	11,298	303.707	2.416	T
2	12,833	332.478	2.239	T
3	10,625	263.385	2.134	C
4	9,375	313.499	2.087	?
5	13,925	328.887	2.084	S
6	12,750	316.446	2.044	S
7	13,750	303.917	2.031	T
8	12,688	394.413	2.017	T
9	12,625	360.104	1.989	T
10	11,875	291.627	1.959	T
12	9,000	319.112	1.924	T
11	11,325	255.701	1.907	T
13	11,500	278.587	1.868	T
14	12,000	321.560	1.861	C
15	13,000	268.640	1.851	T
16	8,650	308.395	1.851	T
18	10,500	270.993	1.852	S
17	11,000	348.783	1.805	?
19	11,375	279.050	1.786	C
20	11,625	302.596	1.785	C
22	9,250	267.809	1.783	C
21	10,950	308.397	1.728	C
23	10,625	295.124	1.726	C
24	8,800	287.729	1.690	T
28	10,688	261.330	1.675	S
25	10,375	239.878	1.654	?
26	11,750	246.967	1.626	?
27	7,938	274.778	1.612	T
30	11,438	267.292	1.570	C
29	10,250	208.488	1.525	C
31	10,500	204.786	1.456	T
32	9,075	237.878	1.406	T
33	9,500	227.033	1.341	T
Average	10,996	287.557	1.826	
Std. dev.	1,508	42.095	.239	
Range	7,938-13,925	205-394	1.341-2.416	
95 percent exclusion limit[3]	7,696	—	—	
Design value[4]	3,665	287.557	—	

[1]Burke and Koch 1987
[2]See figure III-21
C = flange compression failure
T = flange tension failure
S = web interlaminar shear failure adjacent to flange-web joint
? = failure type not recorded.
[3]The probability is 95 percent that at least 95 percent of the maximum resistive moments (based on loads at failure) of the distribution from which this sample was drawn will exceed the values tabulated. These exclusion limits were calculated according to Natrella (1963).
[4]95 percent exclusion limit divided by 2.1.

Surprisingly, the joist EI values were not closely correlated with dry-dowel moduli of elasticity (fig. III-17). For joists 9[1]/2 inches deep, R^2 = 0.541; for joists 11[7]/8 inches deep, R^2 = 0.427. In other words, modulus of elasticity of the dry flange dowels, before semisquaring and grooving, accounted for only about half the variation in stiffness of the joists.

Maximum resistive moment of the joists had even less correlation with dry-dowel moduli of elasticity (fig. III-18). For joists 9[1]/2 inches deep, R^2 = 0.141; for joists 11[7]/8 inches deep, R^2 = 0.229 .

III-10 THE FLANGE-WEB JOINT

Good integrity and strength of the flange-web joint is essential to attainment of high strength and stiffness in the entire joist. As described in section III-2, flakeboard webs of appropriate design probably yield stiffer and stronger joists than plywood webs of the same thickness. But flakeboard can be made with two different flake orientations (random and oriented), and in a range of densities—so generalities regarding performance of flakeboard webs must be made with caution.

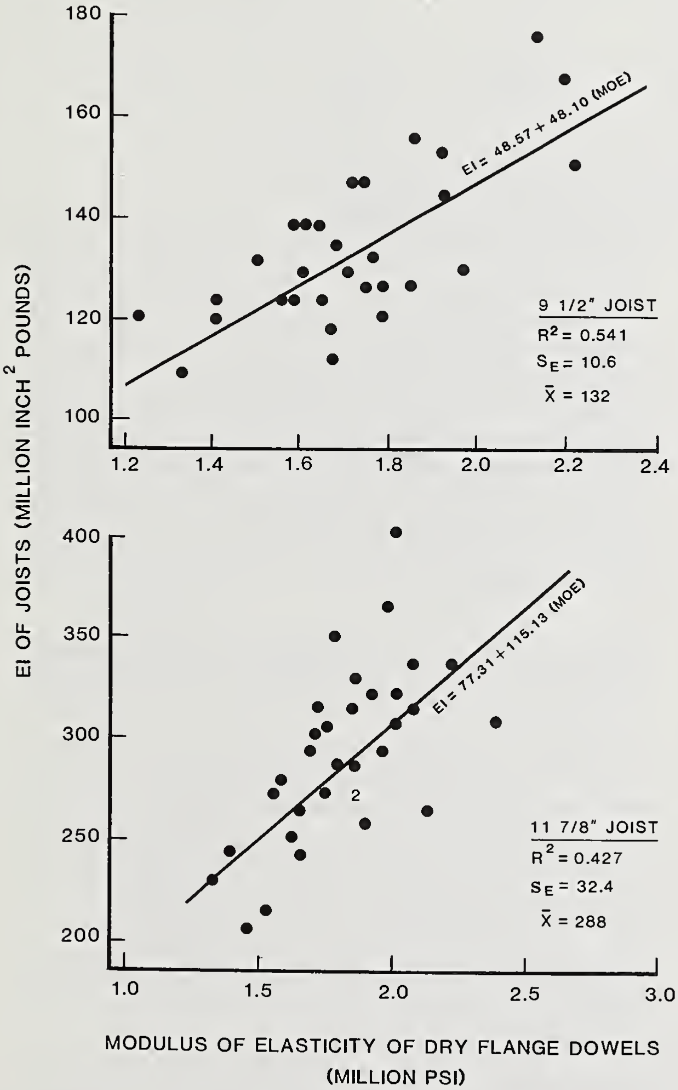

Figure III-17—Relationship between EI of pole joists and modulus of elasticity of flange dowels, both at 10 percent moisture content. (Top) Joists 9[1]/2 inches deep. (Bottom) Joists 11[7]/8 inches deep.

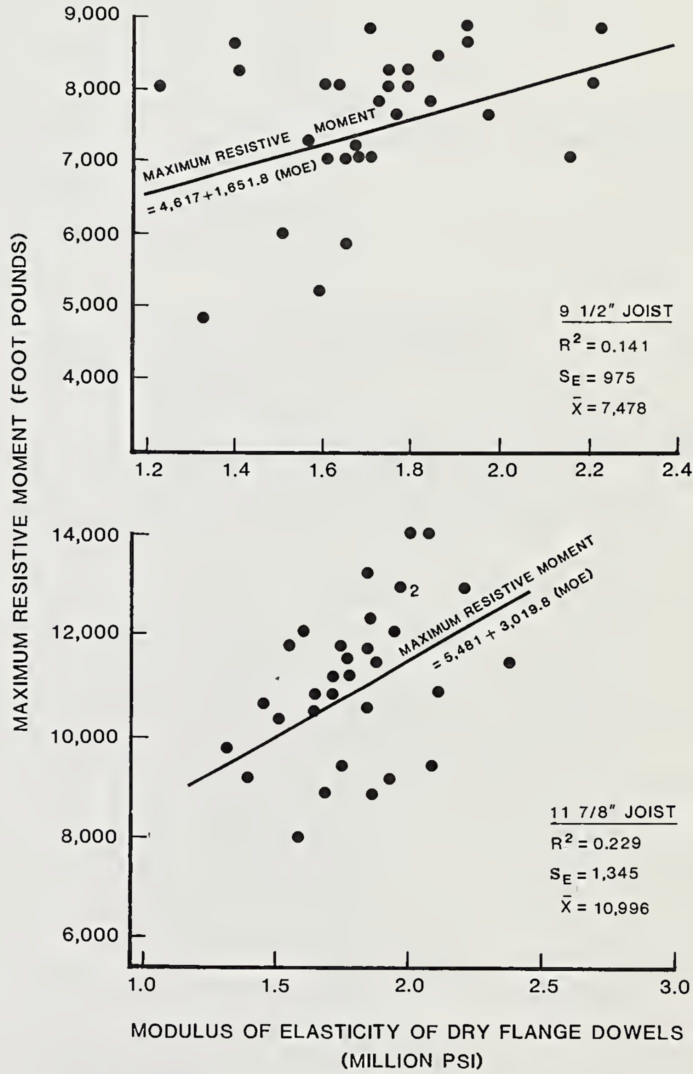

Figure III-18—Relationship between maximum resistive moment of pole joists and modulus of elasticity of flange dowels, both at 10 percent moisture content. (Top) Joists 9[1]/2 inches deep. (Bottom) Joists 11[7]/8 inches deep.

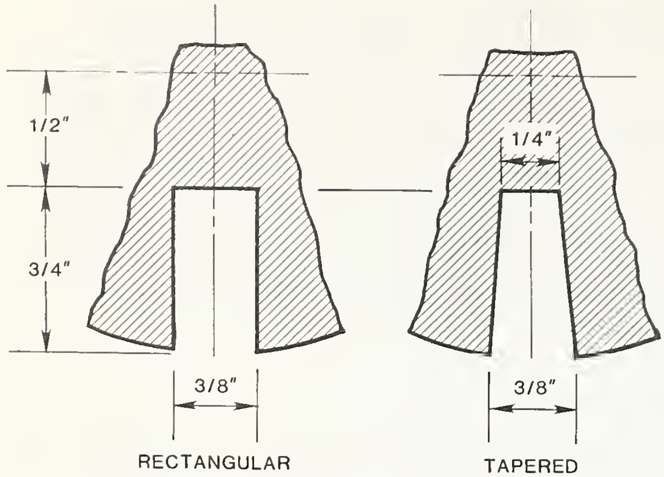

Figure III-19—Comparison of rectangular and tapered grooves for web-flange joint.

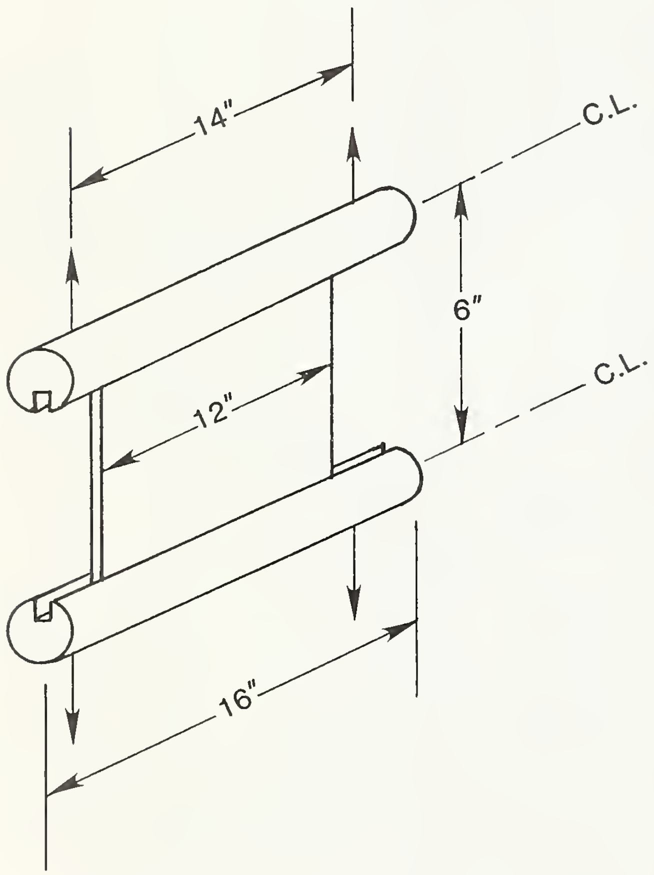

Figure III-20—Specimen and loads applied to evaluate strength of web-flange joints.

Additionally, the dado groove in the flange (and web edge) can be rectangular (fig. III-16) or tapered (fig. III-19). In an effort to obtain some empirical data on the strength of various designs, a two-factor experiment was executed in which the various flange-web joints were glue-assembled and tested to failure in tension (fig. III-20). In this experiment factors were as follows:

Type of flakeboard:	Lodgepole pine OSB with face flakes vertical in joist
	Aspen flakeboard with random orientation of flakes (it was necessary to use aspen because random flake arrangement was not available in lodgepole pine)
Shape of dado groove and web edge:	Rectangular, 0.75-inch deep Tapered, 0.75-inch deep
Replications:	6 to 8

This simple tension test—which yields stresses only partially similar to those incurred in a loaded joist—suggested that there is little difference in strength (stressed as depicted in figure III-20) between joints made with oriented strand board and random flakeboard webs, or between joints made with rectangular and tapered grooves (table III-7).

Because random flakeboard has higher inplane shear strength than oriented strand board of the same density, and because the tapered joint is easier to assemble and has more tendency to self lock on assembly than the rectangular joint, webs with random flake arrangement and tapered joints were chosen for the proposed commercial designs (fig. 3-2, page 28).

III-11 PROOF TESTS OF PROPOSED COMMERCIAL DESIGNS (50 JOISTS)

Based on all of the foregoing discussion, the proposed commercial designs (fig. 3-2) utilize dowels turned when green to a diameter of 2.69 inches (yielding a diameter of about 2.60 inches when dowels are dried to 8 to 10 percent moisture content). A web of $^3/_8$-inch-thick flakeboard with randomly oriented flakes has edges tapered to match tapered dado grooves (figs. 3-2 and III-19, right) in the semicylindrical flanges. (The aspen waferboard with randomly oriented flakes used for proof tests had density of 42.5 lb/ft^3 at 3.45 percent moisture content and averaged 0.365 inch in thickness.)

The lodgepole pine trees utilized for flange dowels in the proof tests were sampled about 25 miles east of Libby, MT, from the Miller Creek drainage. Summary statistics on these dowels are tabulated at the end of section 4-1 and graphed in figures 4-3 through 4-7.

Table III-7—Maximum load sustained in tension (fig. III-20) by flange-web joints with two groove types and two types of flakeboard webs $^3/_8$-inch thick

Replication	Rectangular dado groove OSB[1]	Rectangular dado groove Random flake arrangement[2]	Tapered dado groove OSB[1]	Tapered dado groove Random flake arrangement[2]
	----- *Pounds* -----		----- *Pounds* -----	
1	1,810	1,690	1,080	1,670
2	1,810	1,300	1,520	1,860
3	1,270	1,530	1,590	1,680
4	1,730	1,670	1,370	2,060
5	1,540	1,370	1,500	1,580
6	1,370	1,490	1,880	1,430
7	1,890	—	1,720	1,480
8	—	—	1,660	1,410
Average	1,631	1,508	1,540	1,646
Std. dev.	241	157	241	225
n	7	6	8	8

[1]Lodgepole pine OSB weighing 39.9 lb/ft^3 at test moisture content of about 6 percent of ovendry weight. Flange moisture content was about 8 percent. Face flakes were oriented vertically in the test section, that is, perpendicular to the grain of the flange.
[2]Aspen flakeboard with random flake arangement, and weighing 43.2 lb/ft^3 at test moisture content of 7 to 8 percent of ovendry weight. Flange moisture content was about 8 percent.

Dry dowels with modulus of elasticity of less than 1.5 million lb/in^2 were rejected as unsuitable for flanges. The suitable dowels had average static modulus of elasticity measured in bending (center-point loading over a 15-foot span) of 1.999 million lb/in^2, with range from 1.526 to 2.841 million lb/in^2. By MOE class (at 10 percent moisture content), distribution of values for the 100 suitable dowels was as follows:

MOE class	Number of dowels
Million lb/in^2	
1.50-1.59	4
1.60-1.69	9
1.70-1.79	11
1.80-1.89	14
1.90-1.99	14
2.00-2.09	13
2.10-2.19	13
2.20-2.29	10
2.30-2.39	6
2.40-2.49	2
2.50-2.59	2
2.60-2.69	1
2.70-2.79	0
2.80-2.89	1
Total number	100

To provide a statistical basis for determining design values of mechanical properties of the proposed commercial joists, twenty 10-inch, twenty 12-inch, five 14-inch, and five 16-inch joists 16 feet long were fabricated (fig. 3-2), with these 100 selected flange dowels randomly paired for each joist. The 50 joists were then tested in bending to destruction with center-point loading over a 15-foot span. Results are summarized in table III-8.

III-12 CONCLUSIONS (FROM TABLE III-8)

Three parameters are of particular interest to designers of structural systems utilizing fabricated joists: stiffness (EI), design values for maximum allowable vertical shear loads, and design values for maximum allowable resistive moment.

Stiffness (EI)

Measured joist EI averaged about 79 percent of the product of cylindrical flange-dowel MOE and moment of inertia of flattened and grooved flange-pairs only as spaced in joists of the four depths, but this percentage varied inversely with joist depth, as follows:

Joist depth	Average flange MOE	Flange-pair I
Inches	*Million lb/in^2*	*Inch^4*
10	1.986	149.0
12	2.060	235.2
14	1.941	340.9
16	1.858	466.1

Measured EI (table III-8)	Flange- pair I times flange MOE	Ratio
Million inch^2 pounds	*Million inch^2 pounds*	*Percent*
253	296	85.5
387	485	79.8
516	662	77.9
636	866	73.4
		Average 79.2

Vertical Shear

The twenty 12-inch joists all failed in interlaminar web shear, with values approximating a normal distribution. Only six of the twenty 10-inch joists failed in interlaminar web shear (plus one by web buckling), but if the conservative assumption is made that all 20 supported maximum loads in shear equal to the values tabulated in table III-8, the distribution of these values is as follows:

Maximum-load class	10-inch joists	12-inch joists
Pounds	*Number*	
4,100-4,299	ii	i
4,300-4,499	iii	
4,500-4,699	ii	ii
4,700-4,899	iiiii	iiii
4,900-5,099	ii	iiiii
5,100-5,299	i	iii
5,300-5,499	i	i
5,500-5,699	iii	i
5,700-5,899		ii
5,900-6,099		i

If normality of distribution of these maximum loads is accepted, the procedure of Natrella (1963) can be applied to calculate the 95 percent exclusion limits of maximum center-point loads at web shear failure. Thus the probability is 75 percent that at least 95 percent of the maximum center-point loads at web shear failure of the distribution from which this sample was drawn will exceed the following values:

10-inch $4{,}869 - 1.933 \times 463 = 3{,}974$ pounds
12-inch $5{,}097 - 1.933 \times 464 = 4{,}200$ pounds

These center-point loads correspond to the reaction-point loads (vertical shear loads) and design vertical shear loads—that is, the 95 percent exclusion limit divided by the factor 2.1, as follows:

Joist depth	95 percent exclusion limit for reaction-point load	Design value for vertical shear
Inches	*Pounds*	*Pounds*
10	1,987	946
12	2,100	1,000

Numbers of 14-inch and 16-inch joists tested were insufficient to establish the design values for maximum shear, but the averages (table III-8) suggest that they will sustain no more vertical shear load (and possibly less) than the 12-inch joists. Pending additional tests, the design vertical shear load for the 14-inch and 16-inch joists is assumed to be 1,000 pounds.

Design Resistive Moment

The design value for maximum resistive moment of the 10-inch joists can be conservatively estimated from the center-point loads at failure (table III-8) by Natrella's (1963) procedure for computing the 95 percent exclusion limit (at 75 percent probability), dividing this value by 2 to get the reaction-point load, multiplying by the 7.5-foot moment arm, and dividing the result by the factor 2.1. This procedure yields a design resistive moment for the 10-inch joist as follows:

$$[(4{,}869 - 1.933 \times 463)/2] \times 7.5/2.1 = 7{,}096 \text{ foot pounds}$$

Because all of the joists 12, 14, and 16 inches deep failed by interlaminar web shear, their design resistive moments must be computed from the maximum fiber stress in the 10-inch joists at design resistive moment. Because all flange dowels were randomly drawn from the same dowel population (compare flange MOE's for the four joist depths to perceive this comparability), it is reasonable to assume all can safely carry this same extreme fiber stress at design resistive moment.

For the 10-inch joists, this extreme fiber stress (S) is computed from the relationship:

$$S = MC/I$$

where:
M = design resistive moment, inch-pounds
C = distance from neutral axis to extreme fiber, inches
I = moment of inertia of the flange pair (ignoring web), inches^4

Thus:
$$S = (7{,}096 \times 12)(5)/149.0 = 2{,}857 \text{ lb/in}^2$$

Design resistive moments can then be computed as follows:

Joist depth	Design S	I of flange-pair
Inches	*Lb/in^2*	*Inches^4*
10	2,857	149.0
12	2,857	235.2
14	2,857	340.9
16	2,857	466.1

Joist depth	C	Design resistive moment SI/C	Design resistive moment SI/C
Inches	*Inches*	*Inch-pounds*	*Foot-pounds*
10	5	85,152	7,096
12	6	111,994	9,333
14	7	139,136	11,595
16	8	166,456	13,871

III-13 SUMMARY

Table III-9 summarizes important properties of joists (fig. 3-2) of the four depths.

These data indicate that the joists proposed (fig. 3-2) warrant acceptance by major building code agencies because of their light weight and the uniformity and predictability of their mechanical properties. Probably greater numbers of the joists must be built in longer lengths (incorporating finger joints in the flange dowels) and tested, but the authors are confident that the properties outlined in table 3-3 can be achieved.

Among other things, the data show that small lodgepole pine in northwestern Montana have outstanding mechanical properties for the species. The Libby-Troy area is an optimum site for a manufacturing plant that would utilize this raw material.

Table III-8—Data on 16-foot-long fabricated joists 10, 12, 14, and 16 inches deep (fig. 3-2) static tested in bending over a 15-foot span with center-point loading, and data on the dowels comprising their flanges[1,2]

	Joist data				Flange data[3]		
Joist number	EI[4]	Maximum load[4]	Failure type[5]	O.D. weight per lineal foot	MOE[4]	Specific gravity[6]	Rings per inch
	Million inch^2 pounds	*Pounds*		*Pounds*	*Million lb/in^2*		
			110-inch-Deep Joists				
1	303	5,605	S	2.67	2.262-2.197	0.461-0.438	23-18
2	247	4,540	T	2.53	1.555-2.107	0.407-0.442	15-18
3	243	4,867	S	2.62	2.254-1.711	0.454-0.406	19-15
4	231	4,781	T	2.64	1.744-1.913	0.434-0.466	14-13
5	238	4,486	T	2.54	1.524-2.121	0.381-0.450	14-19
6	257	5,494	T	2.59	1.879-2.012	0.409-0.438	19-15
7	267	4,822	T	2.73	1.765-2.484	0.414-0.478	12-23
8	268	4,767	C	2.60	2.299-1.994	0.448-1.424	20-20
9	241	5,279	T	2.57	1.822-1.803	0.421-0.431	12-18
10	230	4,907	C	2.57	2.115-1.526	0.449-0.404	14-18
11	263	4,236	T	2.41	1.668-1.849	0.387-0.384	13-16
12	247	4,436	T	2.67	1.885-1.966	0.460-0.428	14-19
13	242	5,585	S	2.55	2.157-1.787	0.413-0.423	17-17
14	275	4,594	S	2.74	1.771-2.610	0.416-0.498	18-23
15	248	5,051	S	2.56	2.226-1.759	0.436-0.408	16-14
16	240	4,332	T	2.60	1.594-2.564	0.389-0.464	12-24
17	269	5,689	B	2.74	2.457-2.053	0.489-0.432	24-16
18	244	4,870	C	2.58	1.946-1.864	0.410-0.436	16-12
19	253	4,898	C	2.66	2,358-1.693	0.447-0.426	19-12
20	263	4,143	S	2.59	2.093-2.030	0.417-0.429	21-16
Average	253	4,869		2.61	1.969-2.002	0.427-0.435	16.6-17.3
Std. dev.	17.5	463		0.08	0.288-0.289	0.028-0.027	3.6-3.5
Range	230	4,143		2.41	1.524 1.526	0.381 0.384	12 12
	to	to		to	to to	to to	to to
	303	5,689		2.74	2.457 2.610	0.489 0.498	24 23
			12-inch-Deep Joists				
1	387	5,802	S	2.82	2.146-1.931	0.437-0.409	17-17
2	378	6,095	C?	2.81	2.134-1.754	0.451-0.429	15-13
3	378	5,061	S	2.86	1.791-2.159	0.463-0.430	14-15
4	387	5,770	S	2.89	2.111-2.090	0.458-0.435	15-15
5	452	4,160	S	2.83	2.168-2.145	0.425-0.455	17-14
6	388	5,254	S	2.80	2.025-2.238	0.429-0.437	15-20
7	384	5,162	S	2.83	2.016-1.899	0.446-0.426	15-18
8	372	4,913	S	2.85	1.675-2.267	0.407-0.467	12-14
9	408	5,284	S	2.89	2.336-2.083	0.458-0.435	20-13
10	361	4,638	S	2.78	2.122-1.990	0.410-0.430	14-21
11	368	4,711	S	2.78	1.638-2.295	0.405-0.439	18-19
12	404	4,709	S	2.97	2.029-2.281	0.468-0.468	18-22
13	437	5,061	S	2.92	2.275-2.133	0.467-0.462	20-18
14	390	4,660	S	2.94	1.815-2.578	0.426-0.488	13-23
15	363	4,879	S	2.85	1.925-1.909	0.455-0.438	13-15
16	412	5,617	S	3.00	2.841-1.809	0.515-0.422	24-18
17	375	5,028	S	2.81	1.767-2.055	0.431-0.426	15-19
18	359	4,941	S	2.68	2.054-1.817	0.414-0.401	15-16
19	348	4,858	S	2.77	1.912-2.041	0.425-0.413	17-17
20	383	5,342	S	2.83	1.843-2.286	0.393-0.454	18-18
Average	287	5,097		2.85	2.031-2.088	0.439-0.438	16.2-17.2
Std. dev.	25.7	464		.07	0.270-0.204	0.029-0.022	2.9-2.9
Range	348	4,160		2.68	1.638 1.754	0.393 0.401	12 13
	to	to		to	to to	to to	to to
	452	6,095		3.00	2.841 2.578	0.515 0.488	24 23

(con.)

Table III-8 (Con.)

Joist number	EI[4]	Maximum load[4]	Failure type[5]	O.D. weight per lineal foot	MOE[4]	Specific gravity[6]	Rings per inch
	Joist data				Flange data[3]		
	Million inch² pounds	Pounds		Pounds	Million lb/in²		
			14-inch-Deep Joists				
1	460	3,860	S	2.98	1.918-1.615	0.459-0.412	12- 8
2	558	4,396	S	2.94	1.653-1.818	0.408-0.444	9-10
3	530	4,979	S	3.00	2.086-2.247	0.424-0.440	16-15
4	494	—	-	2.95	1.670-2.182	0.402-0.439	14-17
5	538	5,456	S	3.20	1.867-2.355	0.416-0.477	12-18
Average	516	4,673		3.01	1.839-2.043	0.422-0.442	12.6-13.6
Std. dev.	38.9	694		0.11	0.181-0.313	0.022-0.023	2.6- 4.4
Range	460	3,860		2.94	1.653 1.615	0.402 0.412	9 8
	to	to		to	to to	to to	to to
	558	5,456		3.20	2,086 2.355	0.459 0.477	16 18
			16-Inch-Deep Joists				
1	653	4,274	S	3.13	1.914-1.635	0.457-0.409	15- 9
2	560	5,522	S	3.19	1.638-1.819	0.404-0.455	11-11
3	645	4,911	S	3.23	1.983-1.936	0.448-0.437	12-18
4	620	4,384	S	3.09	1.736-1.856	0.410-0.415	13-19
5	700	4,932	S	3.20	1.736-2.322	0.400-0.465	13-16
Average	636	4,805		3.17	1.801-1.914	0.424-0.436	12.8-14.6
Std. dev.	51.2	500		0.06	0.142-0.254	0.027-0.024	1.5-4.4
Range	560	4,274		3.09	1.638 1.635	0.400 0.409	11 9
	to	to		to	to to	to to	to to
	700	5,522		3.23	1.914 2.322	0.457 0.465	15 19

[1]Burke, Edwin, J; Koch, Peter. 1987 January 9. Properties of 2¼- and 2½-inch lodgepole pine dowels from northwest Montana stands and of 9½- and 11⅞-inch-deep joists made with these dowels as flanges. Study WSL #19A. Unpublished data on file at Wood Science Laboratory, Inc. Corvallis, MT.

[2]Flanges were pith-centered lodgepole pine dowels measuring 2.60 inches in diameter when at 10 percent moisture content. Webs were aspen waferboard with random flake orientation, 0.365 inch thick, and weighing 40.5 lb/ft³ at 3.45 percent moisture content. At joist test, moisture content of the joist components averaged as follows (percent of ovendry weight): flanges 9.6 percent; webs 4.5 percent. Principally because web proportion increases with joist depth, moisture content of entire joists at test decreased with increased depth, as follows: 10-inch, 8.5 percent; 12-inch, 8.3 percent; 14-inch, 6.7 percent; and 16-inch, 6.5 percent.

[3]Tabulations in these columns show values for the tension flange followed by values for the compression flange. MOE of flanges was measure by non-destructively testing the dry dowels (before flattening of tops or grooving for webs) in bending over a 15-foot span with a 28-pound center-point load superimposed on a 10-pound preload.

[4]Static tested and values adjusted to correspond to a flange moisture content of 10 percent of ovendry weight according to procedures defined in American Society for Testing and Materials [ASTM} 1972a,1972b.

[5]See figure III-21.

C = flange compression failure
T = flange tension failure
S = web interlaminar shear failure adjacent to flange-web joint
B = web buckling failure adjacent to load head.

[6]Based on green volume and ovendry weight.

Table iii-9—Summary tabulation of important properties of the proposed joists (fig. 3-2)

Property	10-inch	12-inch	14-inch	16-inch
Depth, inches	10	12	14	16
Weight per lineal foot, ovendry	2.61	2.85	3.01	3.17
Average EI, million inch² pounds	253	387	516	636
Maximum vertical shear at 100 percent of design load	946	1,000	1,000	1,000
Maximum resistive moment at 100 percent of design load, foot pounds	7,096	9,333	11,595	13,871

Figure III-21—Principal modes in which the fabricated joists failed under load. (Top) Flange tension failure. (Center) Flange compression failure. (Bottom) Web interlaminar shear failure in vicinity of web-flange joint.

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Koch, Peter; Keegan, Charles E., III; Burke, Edwin J.; Brown, Darrell L. 1989. Proposed wood products plant to utilize sub-sawlog size and dead lodgepole pine in Northwestern Montana—a technical and economic feasibility analysis. Gen. Tech. Rep. INT-258. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 145 p.

Describes and evaluates technical and economic feasibility of a proposed wood products plant utilizing sub-sawlog-size and dead lodgepole pine in northwestern Montana. Primary purpose of the plant is to facilitate harvesting and reforestation of vast, stagnated stands at minimal public expense. Annual stemwood consumption would total 200,000 tons, ovendry basis. Output would comprise fabricated joists, edge-glued panels for millwork, oriented-strand board, tree props, and studs. The plant would employ 271 mill workers, plus woods and transport workers. Capital investment is estimated to be $62 million; net annual sales, $40 million; after-tax annual rate of return, about 25.1 percent—based on an equity of $31 million (assuming an additional $31 million is raised through sales of bonds).

KEYWORDS: forest management, forest products, timber management, manufacturing plants, wood utilization, stand replacement, lodgepole pine, joists, millwork, flakeboard

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